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JOINT AIR POLLUTION STUDY OF ST. CLAIR - DETROIT RIVER AREAS FOR INTERNATIONAL JOINT COMMISSION CANADA AND THE UNITED STATES

International Joint Commission-
United States and Canada

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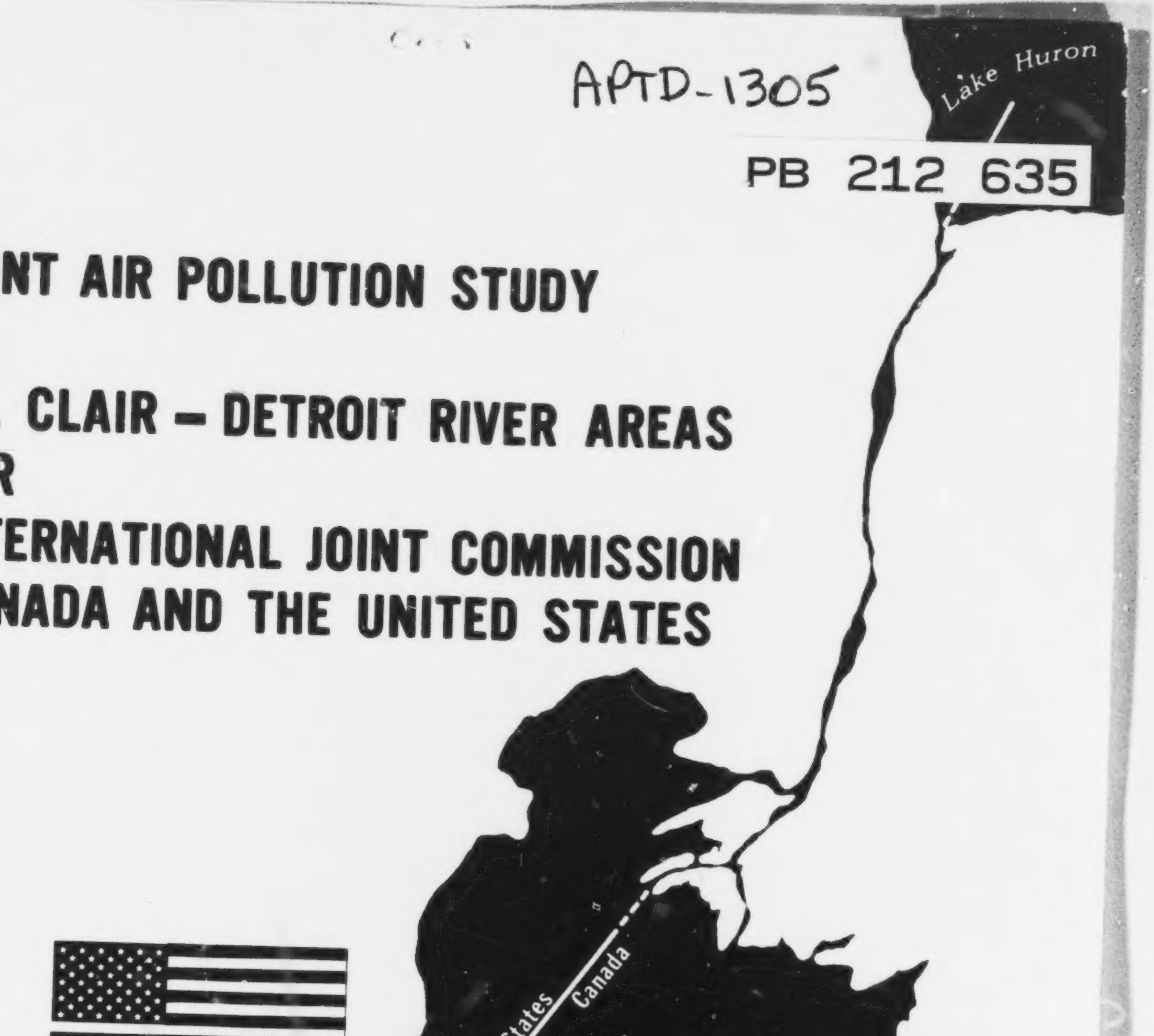
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As a result of a request, by the City of Windsor, that action be taken to abate the flow of transboundary-pollution emanating from the industrial complex in Wayne County, Michigan, the Governments of Canada and the U.S. initiated an investigation. During this investigation of the air pollution, the following work was undertaken: 1. Air quality measurements were made on both sides of the international boundary at approximately 80 locations. The following pollutants and effects were sampled: Particulate matter; Sulfur dioxide; Hydrocarbons; Fluorides; Carbon monoxide; Sulfation rates; Hydrogen sulfide; Nitrogen oxides; and Oxidants. In addition, samples of suspended particulates were analyzed quantitatively for 16 metals. Odorous pollutants were investigated in a special survey. An aircraft was instrumented and flown along the boundary to measure directly the flux of pollutants across the boundary. 2. Meteorological measurements were taken at 15 locations. 3. An inventory of atmospheric emissions was made of pollutants emanating from all sources. 4. A study of the effects of air pollutants in the area on selected vegetation and materials was conducted. This volume describes the methods of evaluation and presents the results and conclusions.

17. Key Words and Document Analysis. 17a. Descriptors

Air Pollution
Measurement
Surveys
Design Criteria
Emission
Inventories
Sulfur Dioxide
Partic[illegible]
Standards
Meteorology
Dust
Sampling
Hydrogen Sulfide
Hydrocarbons
Fluorides
Carbon Monoxide
Fuel Consumption
Nitrogen Oxides
Oxidizers
Sulfation
Vegetation
Odors
Dispersion
Industrial Plants
Expenses

17b. Identifiers/Open-Ended Terms

St. Clair-Detroit Area
Michigan
Canada
Port Huron-Sarnia Area
Detroit-Windsor Area
Particulates
Odors
Air Quality
Air Pollution Detection
Suspended Particulates
Air Pollution Effects-Materials
Air Pollution Control Programs
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OF ST. CLAIR–DETROIT RIVER AREAS
FOR INTERNATIONAL JOINT COMMISSION
CANADA AND THE UNITED STATES

Conducted by the
St. Clair–Detroit Air Pollution Board
and Cooperating Agencies

INTERNATIONAL JOINT COMMISSION
Ottawa
and
Washington
January 1971

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The St. Clair–Detroit Air Pollution Board and its cooperating agencies are responsible for the contents of this report. The Board expresses gratitude to the Environmental Protection Agency for publication of the report.

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Ottawa 4, Ontario, Canada

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1711 New York Avenue, N. W.
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SUMMARY: INVESTIGATIONS, RESULTS AND CONCLUSIONS, AND RECOMMENDATIONS

Air pollution in the Detroit — Windsor area has been a cause of public concern for many years. As a result of this concern, the City of Windsor in 1964 requested of the Government of Canada, through the Province of Ontario, that action be taken to abate the flow of transboundary pollution emanating from the industrial complex in Wayne County, Michigan.

The Governments of Canada and the U. S., in considering this matter, decided to extend the geographical area of consideration because of complaints in the Port Huron, Michigan, area of a transboundary flow of air pollution emanating from the industrial complex in the Sarnia, Ontario, area.

Accordingly, the Governments referred this matter, in September 1966, to the International Joint Commission for investigation of the following questions:

1. Is the air in the vicinity of Port Huron — Sarnia and Detroit — Windsor being polluted on either side of the international boundary by quantities of contaminants that are detrimental to the public health, safety, or general welfare of citizens or that are detrimental to property on the other side of the international boundary?
2. If the first question or any part of it is answered in the affirmative, what sources contribute to this pollution and to what extent?
3. If the Commission should find that any sources on either side of the boundary in the vicinity of Port Huron - Sarnia and Detroit - Windsor contribute to air pollution on the other side of the boundary to an extent detrimental to the public health, safety, or general welfare of citizens or detrimental to property, what preventative or remedial measures would be most practical from economic, sanitary, and other points of view? The Commission should give an indication of the probable total cost of implementing the measures recommended.

INVESTIGATIONS

The Commission established in November 1966 the St. Clair - Detroit Air Pollution Board to conduct on its behalf an investigation to answer the questions referred to the Commission by Canada and the U. S.

In conducting this study, the Board utilized the facilities and manpower of the following participating agencies:

1. National Air Pollution Control Administration - Department of Health, Education, and Welfare - U. S.
2. Environmental Health Directorate - Department of National Health and Welfare - Canada

3. Air Management Branch - Department of Energy and Resources Management - Ontario, Canada
4. Division of Occupational Health - Department of Public Health - Michigan, U. S.
5. Air Pollution Control Division - Department of Health - Wayne County, Michigan, U. S.

Cooperation was obtained from municipalities in Ontario as well as from municipal agencies in Michigan.

During the 1968 study period the following work was undertaken:

1. Air quality measurements were made on both sides of the international boundary at approximately 80 locations. The following pollutants and effects were sampled:

   Particulate matter
   Sulfur dioxide
   Hydrocarbons
   Fluorides
   Carbon monoxide
   Sulfation rates
   Hydrogen sulfide
   Nitrogen oxides
   Oxidants

   In addition, samples of suspended particulates were analyzed quantitatively for 16 metals. Odorous pollutants were investigated in a special survey. An aircraft was instrumented and flown along the boundary to measure directly the flux of pollutants across the boundary.
2. Meteorological measurements were taken at 15 locations.
3. An inventory of atmospheric emissions was made of pollutants emanating from all sources.
4. A study of the effects of air pollutants in the area on selected vegetation and materials was conducted.

For the preparation of this report, the following methods of evaluation were used:

1. Production of pollution roses that show the frequency of wind directions along with selected pollution levels at measuring stations, thus indicating the frequency of the transboundary flow of pollutants.
2. Case studies of the wind direction that accompanied the occurrence of levels of pollution in excess of concentrations that cause adverse effects.
3. Use of a mathematical dispersion model to compute the average concentrations on the opposite side of the boundary that result from transboundary flow.
4. Direct measurements of the transboundary flux of pollution by measurements taken on an instrumented aircraft.

RESULTS AND CONCLUSIONS

Because of the mass of information collected, all the data have not been analyzed; however, sufficient analysis has been performed to warrant the following conclusions:

1. A transboundary flow of air pollutants does occur across both the St. Clair and Detroit River international boundaries in the vicinities of Port Huron - Sarnia and Detroit - Windsor, producing pollution levels that are in excess of desirable air quality standards already established in Ontario and about to be established in Michigan. Although many pollutants were measured, particulates and SO_x only were used in this evaluation because of their magnitude and obvious relationship to area and point sources. It has been determined that SO_x and particulate pollution does exist and, in some regions of the study, pollution is being transported across the international boundary to an extent detrimental to the other country. In the Detroit - Windsor area, far more SO_x and particulate pollution is being transported from the U. S. into Canada than from Canada into the U. S. In the Port Huron - Sarnia area, transboundary pollution was also verified; however, the contributions from the respective countries were approximately equal.
2. In addition to pollution from transboundary flow of air pollutants, certain areas in both the U. S. and Canada are experiencing levels of air pollution in excess of their air quality standards because of sources located in their respective jurisdictions.
3. Transboundary and local pollution both exceed the level that is detrimental to the health, safety, and general welfare of citizens, and to property on the other side of the international boundary.

Detroit – Windsor Area

Sulfur Dioxide - The dispersion model estimates show that the combined contributions of U. S. point and area sources to the annual average SO_2 concentrations in the Windsor, Ontario, area reached values as high as 0.04 ppm (Station 203), well above the acceptable annual average value of 0.02 ppm set by the Ontario standards. On the other hand, the combined contributions of Canadian point and area sources to annual average SO_2 pollution concentrations in the Detroit, Michigan, area were found to be insignificant except for some minor effects in the vicinity of Belle Isle and Grosse Point, Michigan. In the Detroit – Windsor area, there were 17 continuous SO_2 analyzers, 11 in Detroit, and 6 in Windsor. All 17 stations reported annual average SO_2 concentrations equal to or greater than 0.02 ppm. Three of the Detroit stations and two Windsor stations reported annual averages equal to or greater than 0.03 ppm.

Particulates - The dispersion model estimates show that the combined contributions of U. S. area and point sources to the annual average concentrations of particulates in the Windsor area were very significant. U.S. sources contribute the equivalent of at least the entire annual average particulate concentration loadings allowed under Ontario standards (60 $\mu g/m^3$) for a large portion of the Windsor area. For some sections of the area, particulate pollution from the U. S. exceeds 140 $\mu g/m^3$.

An analysis of the particulate pollution roses for stations in Windsor shows a relatively high frequency of occurrence of pollution associated with westerly winds. This association tends to implicate as a source the heavily industrialized U.S. area of Zug Island and the southern section of the city of Detroit.

A case study of Station 203 in Windsor showed that soiling indices exceeding 2.0 Coh/1,000 lineal feet occurred most frequently when the wind was from a westerly direction.

The dispersion model estimates show that Belle Isle and the mainland area in the immediate vicinity of Detroit are affected by Canadian area and point sources of particulates. The maximum contributions (20 $\mu g/m^3$) from Canada to the Detroit area, however, averaged well below both the Ontario standards and the proposed Michigan standards.

In the Detroit - Windsor area, suspended particulates were measured at 34 locations. Thirty-three of the 34 locations reported annual means in excess of 60 $\mu g/m^3$. Ten stations in Windsor and 13 in Detroit reported annual means in excess of 80 $\mu g/m^3$. Eight stations each in Detroit and Windsor reported annual means in excess of 100 $\mu g/m^3$.

Port Huron – Sarnia Area

Sulfur Dioxide - The dispersion model estimates indicate that for part of the Canadian area opposite and south of St. Clair, Michigan, SO_2 from U. S. sources equaled or exceeded the concentration limits set by the Ontario standards (0.02 ppm annual average). Outside this affected area, U. S. sources contributed approximately half of the maximum concentration allowed by the Ontario standards.

A case study of Station 156 south of Sarnia showed hourly average concentrations of SO_2 exceeding 0.30 ppm most frequently when the winds were from the south-southwest. The likely source of such pollution is a thermal electric power plant on the U. S. side of the boundary.

Canadian point and area sources were calculated as producing average annual SO_2 concentrations in the extreme eastern portion of the city of Port Huron that equal or closely approach the Ontario standards for residential or rural areas. Elsewhere in the U. S. portion of the area, Canadian contributions to SO_2 pollution were insignificant.

In the Port Huron - Sarnia area, SO_2 was measured continuously at 12 locations. All 12 locations reported annual averages equal to or greater than 0.02 ppm. One station each in Port Huron and Sarnia reported annual averages equal to or greater than 0.03 ppm.

Particulates - Dispersion model estimates for the industrial area south of Sarnia, Ontario, indicate that U. S. point and area sources contributed on an annual average basis more than 35 $\mu g/m^3$ of suspended particulates, or more than one-half of the total concentrations allowed under the Ontario standard. In general, throughout the region north of Sombra, Ontario, and within about 6 miles of the St. Clair River, U. S. sources contributed particulate pollution amounting to approximately one-third of the total concentration allowed under the Ontario standards.

The southeastern portion of Port Huron, Michigan, was calculated as receiving from Canadian point and area sources, on an annual average basis, one-third of the particulate concentrations allowed under the proposed Michigan standards.

The particulate pollution roses for stations in Port Huron - Sarnia suggest a transboundary flow from sources in the petroleum-related industrial complex south of Sarnia and from thermal electric power plants south of Port Huron.

A case study of Station 310 in Port Huron showed 2-hour average concentrations of soiling index in excess of 2.0 Coh/1,000 lineal feet with wind from the south-southeast. Winds from this direction would transport pollution from Canadian sources south of Sarnia across the boundary to the station in Port Huron.

In the Port Huron - Sarnia area, suspended particulates were measured at 22 locations. All 11 stations near Sarnia and 7 of the 11 stations near Port Huron reported annual averages in excess of 60 $\mu g/m^3$. Five stations in Sarnia and two in Port Huron reported annual averages in excess of 80 $\mu g/m^3$. Three stations in the Sarnia area reported annual averages in excess of 100 $\mu g/m^3$.

Odors - There is an odor problem in the Port Huron - Sarnia area that does not lend itself to the quantitative analysis possible in the case of SO_2 and particulates; nevertheless, it does deserve serious consideration.

Odors from industrial operations in the Sarnia area have long been a source of complaints by local residents who live along the bank of the portion of the St. Clair River extending south from Port Huron and Sarnia to Marine City and Sombra. The odors observed in the Port Huron - Sarnia area were considered to be a mixture caused by petroleum refining and petroleum-related organic chemical manufacturing in Sarnia. The "dead fish" odor observed in the Marine City area appears to originate at the Chinook Chemical Company south of Sombra, Ontario.

Odors which fall into the general category discussed above do not have the effects upon health associated with SO_x and particulates. They do have aesthetic effects and can in fact cause a lack of personal well being; if continued over a long period of time, they can indirectly produce ill health.

Air Quality Standards

In analyzing the data, the Board noted discrepancies between the established Ontario and the proposed Michigan ambient air quality standards as follows:

	Michigan (Proposed)	Ontario
SO_x, annual average	0.04 ppm	0.02 ppm
Suspended particulates, annual geometric mean	80 g/m^3	60 g/m^3

Although it is beyond the scope of this Board to resolve these discrepancies, it should be noted that the standards set by Ontario and proposed by Michigan have been used in the body of this report and in the summary to assess the air quality of the respective jurisdictions.

In addition, Ontario has set standards for ten other pollutants for which no comparable limits have yet been fixed in Michigan. Ontario figures, therefore, were used as a guide for evaluating the other pollutants measured.

Although Michigan has not officially promulgated its standards, Michigan officials have advised the National Air Pollution Control Administration that they intend to adopt standards equal to or more stringent than those used in this report. In this connection, it should be clearly noted that the U. S. National Air Pollution Control Administration has approved proposed air quality standards submitted to it by a number of states in various federally-designated Air Quality Control Regions; the approved standards are approximately equal to the Ontario standards for SO_2 and particulates.

It is apparent, then, that the agencies charged with the control of air pollution in the study area have the necessary power to achieve a decrease in air pollution emissions, as evidenced by the reductions of particulate emissions that have been accomplished during the period of study and since its completion.

COSTS

In order to ascertain the costs of implementing remedial measures for the study area, it was necessary to utilize a mathematical model and approach the problem on an area basis.

In general, the steps used to estimate the control costs were:

1. To categorize sources.
2. To identify particulate and sulfur dioxide control alternatives capable of achieving the desired reductions in each category.
3. To estimate the annual cost associated with each alternative.

The estimated total annual costs of controlling sulfur dioxide and particulates for the Detroit-Windsor and Port Huron-Sarnia areas are as follows:

	Estimated Least Annual Cost	
	Low	High
Power plants	$15,479,480	$15,479,480
Industrial boilers	45,585,503	45,588,503
Industrial processes	4,007,595	5,139,573
Total	$65,072,580	$66,204,573

The costs include annualized total costs, operating and maintenance costs, overhead costs, and fuel price differentials.

RECOMMENDATIONS

1. That the responsible control agencies in both countries accelerate their abatement programs to bring all sources into compliance.
2. That the control agencies in both countries report semiannually to the Commission their progress in achieving compliance.
3. That the control agencies in both countries report annually to the Commission the ambient air quality existing in their jurisdictions.

4 That the Commission request the Governments of both countries and their respective air pollution control agencies to establish uniform air quality standards as soon as possible.

5. That the governments of the United States and Canada, together with the State of Michigan and the Province of Ontario, cooperate to control transboundary air pollution from existing sources and to prevent creation of new sources of transboundary air pollution.

6. That with the issuance of the Commission's report, the Board be terminated.

JOINT AIR POLLUTION STUDY
OF ST. CLAIR–DETROIT RIVER AREAS
FOR INTERNATIONAL JOINT COMMISSION
CANADA AND THE UNITED STATES

1. INTRODUCTION

Air pollution in the Port Huron - Sarnia and Detroit - Windsor areas has caused public concern for many years and has been the subject of extensive investigation by several organizations. An earlier study, of the Detroit - Windsor area only, was conducted by the International Joint Commission primarily to assess the extent and effects of vessel smoke on both sides of the international boundary and to make recommendations on remedial action.

The International Joint Commission initiated the investigation described in the present report in response to a request by the Governments of the U.S. and Canada that the Commission inquire into and report on the questions:

1. Is the air in the vicinity of Port Huron - Sarnia and Detroit - Windsor being polluted on either side of the international boundary by quantities of contaminants that are detrimental to the public health, safety, or general welfare of citizens or that are detrimental to property on the other side of the international boundary?
2. If the first question or any part of it is answered in the affirmative, what sources contribute to this pollution and to what extent?
3. If the Commission should find that any sources on either side of the boundary in the vicinity of Port Huron - Sarnia and Detroit - Windsor contribute to air pollution on the other side of the boundary to an extent detrimental to the public health, safety, or general welfare of citizens or detrimental to property, what preventative or remedial measures would be most practical from economic, sanitary, and other points of view? The Commission should give an indication of the probable total cost of implementing the measures recommended.

The geographic region of concern is shown in Figure 1-1.

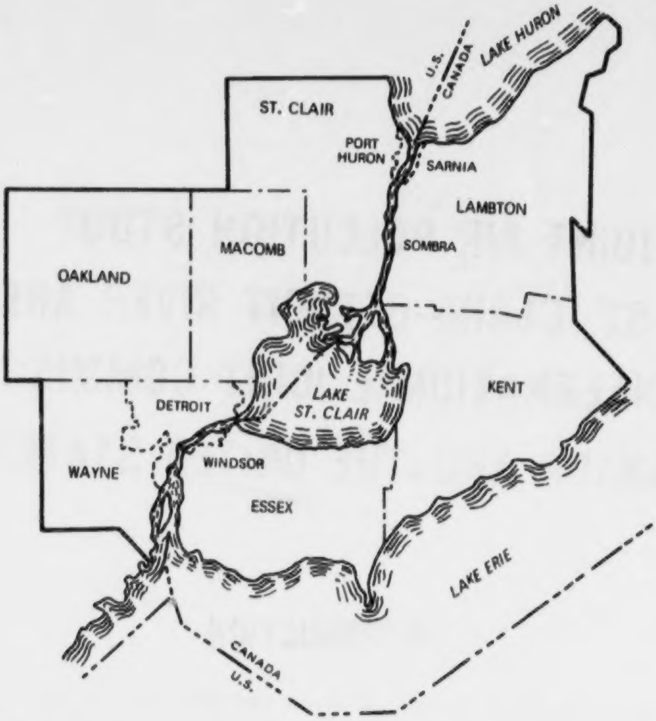


Figure 1-1. Geography of the Port Huron—Sarnia and Detroit—Windsor border area.

To provide the advisory support needed to answer these questions, the Commission in November 1966 formed an Air Pollution Board and designated its responsibilities. The Board was to undertake, through appropriate agencies in Canada and the U. S., any investigations needed to answer the questions. Its first task was to coordinate the resources of participating agencies on both sides of the border, including the two Federal governments, the Province of Ontario, the State of Michigan, and other city and county authorities.

In planning the survey, the Board conducted inspections, by air and on land, of the border areas in question and attended public hearings arranged by the International Joint Commission in Port Huron and Windsor in June 1967. To assist the Board in designing and conducting the study, three advisory committees were formed in June 1967: a transboundary flow committee composed of members with special knowledge of local meteorology and the transport of pollutants; an effects committee composed of members of the medical profession with special knowledge of air pollutants; and an industrial emissions committee composed of engineering representatives from industry and control organizations.

1.1 PREVIOUS STUDIES

The primary objectives established for the study were: to evaluate the extent and effects of transboundary air pollution; to identify the sources on each side of the boundary; and to recommend methods and estimate costs of control. The emphasis placed on the transboundary aspects differentiates this study from previous ones that were concerned mainly with problems within the respective countries. The previous investigation of the Detroit - Windsor area by the International Joint Commission, a task referred to it by the two Governments on January 12, 1948, was undertaken solely to assess the nature, extent, effects, and control of pollution in Detroit and Windsor by vessels on the Detroit River. The report[1] on that study was submitted May 31, 1960. In that Commission report, notwithstanding its primary concern with vessel smoke, the question of transboundary pollution was discussed. It was pointed out that the factors affecting the transboundary flow of pollutants included the location and course of the Detroit River, wind patterns in the area, and the sites of major industrial sources, including vessel traffic. Studies of wind patterns indicated that air pollutants were blown from the U. S. into Canada more frequently than in the reverse direction.

Measurements made in that study indicated a considerable flow of particulates from sources in the River Rouge - Zug Island area of the U. S. into the Ojibway area of Canada. Observations of air movements across the boundary showed that any substantial source of pollution on either side concerns both countries. In conclusion, the Commission also pointed out that industrial, domestic, and transportation activities on land contributed much more to the overall pollution of the atmosphere than did vessels plying the river, and that transboundary air flow was an important factor in that contribution. The Commission concluded, however, that adequate legal and administrative authority existed for enforcing the proper control of emissions from sources other than vessels.

Another study[2] to assess the extent of transboundary pollution affecting the Canadian side of the Detroit River opposite the industrial complex of River Rouge - Zug Island was made for the period September 20 to November 15, 1963. by the Canadian Departments of Transport and National Health and Welfare, and the Province of Ontario Department of Health. Total particulates and iron concentrations were measured at seven sites in the Windsor area. Excessively high concentrations of suspended particulates were found on 49 percent of the days sampled. The 24-hour average iron concentrations were of the same magnitude as the highest found by the U. S. National Air Sampling Network. When the air quality data were related to meteorological data, the highest pollution levels were found to occur when the winds were blowing from the direction of the industrial sources on the Detroit side of the river (Zug Island - Ecorse).

No reports were available that identified and qualified the transboundary air pollution flow in the St. Clair River area. Measurements of the concentrations of several pollutants and of meteorological variables have been made, however, on both sides of the St. Clair River by the Province of Ontario and the State of Michigan. In addition, an industrial group on the Canadian side has measured contaminant levels for many years.

1.2 DESCRIPTION OF THE AREA

The industrial and demographic characteristics of an area are clues to the potential for air pollution. Whether the potential becomes reality is determined in part by the topographical and meteorological characteristics peculiar to an area. An outline of the Detroit - Windsor and Port Huron - Sarnia areas in terms of topography, demography, and meteorology provides a setting for the discussion of air pollution problems.

1.2.1 Topography

The area includes the industrialized sectors along the St. Clair and Detroit Rivers. The rivers connect Lake Huron with Lake St. Clair, and Lake St. Clair with Lake Erie. Lake Huron, with an average elevation of 580 feet above mean sea level, drains southward through the St. Clair River to Lake St. Clair, which has an average elevation of 574 feet. Lake St. Clair drains southwestward from Peach Island to Zug Island and then southward to Lake Erie, which has an average elevation of 572 feet.

The northern area is a flat plain which rises gradually from an elevation of 600 feet at the banks of the St. Clair River to 650 feet about 15 miles east and 10 miles west of the river. The shallow valley of the St. Clair River is narrowest at its Lake Huron end in the vicinity of Port Huron - Sarnia.

The terrain in the vicinity of the Detroit River is nearly flat as well. It rises from 575 feet at the river to 625 feet southeast of Windsor. On the Michigan side, it rises to 600 feet within a short distance of the river banks and increases gradually to nearly 800 feet within 15 to 20 miles from the river.

The nearest hills are about 50 miles away in Michigan with an elevation of about 1,500 feet at the highest point. There are no major terrain elevation differences that would affect the dispersion of pollutants within the areas under study.

1.2.2 Demography

The political subdivisions, shown in Figure 1-1, that are involved in the study are Wayne, Oakland, Macomb, and St. Clair Counties in Michigan, and Essex, Kent, and Lambton Counties in Ontario. The St. Clair River forms the international boundary between St. Clair and Lambton Counties, with Port Huron and Sarnia situated on opposite sides of the river. Essex County is a peninsula bounded by Lake Erie on the south, Lake St. Clair on the north, and the curved course of the Detroit River on the west and northwest. Kent County lies east of both Lake St. Clair and Essex County. Wayne County borders on the entire course of the Detroit River and also on a small part of Lake St. Clair. North of Wayne County are Oakland and Macomb Counties, the latter bordering on Lake St. Clair. Greater Detroit includes generally the northwest half of Wayne County plus adjacent parts of Oakland and Macomb Counties. The city of Windsor borders on the upstream arc of the Detroit River, and urban Detroit spans almost three quadrants northeast, northwest, and southwest of Windsor.

1.2.2.1 United States - Michigan - Wayne, Oakland, and Macomb Counties, considered the Detroit metropolitan area, have more than 4 million inhabitants and over 4,700 manufacturing enterprises. Like other large metropolitan areas, population growth during the past two decades was high but variable. Between

1950 and 1960, explosive suburban growth was accompanied by a slight decline in the city's population.

Wayne County, with an area of 623 square miles, now has a population exceeding 2.75 million, with a projected population of nearly 4 million by the year 2000. The county is highly industrialized, and accounts for 35 percent of U. S. automobile manufacturing.

Oakland County has some 900 square miles, of which 28 percent is urban. By a recent calculation, 54 percent of the county's area will be urban by 1990. The population is now approximately 800,000 and is expected to double by the year 2000. Manufacturing accounts for nearly half of the 195,000 jobs. Only 59 percent of the employed workers who live in the county also work there.

Macomb County has an area of 481 square miles; its population, now over 575,000, is expected to reach 1.6 million by the year 2000. Until 1940, nearly the entire county was agricultural, but the southern portion of the county is undergoing rapid residential, commercial, and industrial development.

St. Clair County has an area of 723 square miles and a population of nearly 110,000. The future urban area in St. Clair County is expected to connect with the Detroit metropolitan area, with the St. Clair population exceeding 250,000 by the year 2000. Manufacturing is the largest part of the county's economy, employing 29 percent of a labor force of over 38,000. The county specializes in four industries: primary metal products, paper products, chemicals, and rubber and plastic products.

1.2.2.2 Canada - Ontario - Essex County has an estimated population exceeding 295,000, with more than 212,000 living in metropolitan Windsor. Windsor, Amherstburg, and Tecumseh, with 222,000 people, are all near the Detroit River. The county population is expected to be more than 460,000 by the year 2000. The manufacturing facilities in the county are located near the border. The labor force was greater than 93,000 in 1961 and was estimated at 106,000 in 1968.

Lambton County has a population of about 115,000, of which over 62,000 live in the Sarnia urban area. The population of the county is expected to grow to 175,000 by the year 2000. Over half of the county's population and work force is near the St. Clair River border. The work force was 37,000 in 1961 and was estimated at over 41,000 in 1968. The major industries are chemicals and oil refining.

1.2.3 Meteorology

This U. S. - Canadian border area, lying between 42 and 43 degrees north latitude and approximately 83 degrees west longitude, has a continental climate characterized by warm summers and cold winters with a moderating influence due to the proximity of the Great Lakes. Wind direction and speed and the stability of the lower atmosphere are the meteorological factors of most significance to the dispersion of air pollutants in this area.

1.2.3.1 Winds - Although the area lies in the zone of the prevailing westerly winds, it is near the mean summertime position of the polar front. Storm systems that move generally eastward are accompanied by northward and southward displacements of the front. Consequently, the spring and summer winds are less consistent than those of fall and winter.

Table 1-1 gives the long-term frequencies of wind direction and average wind speeds at the Detroit City Airport and at the Sarnia Tower. For comparison, the corresponding data are also given for the year of this investigation, December 1967 through November 1968. A graphic comparison, in the form of wind roses that depict the wind direction frequencies for the two periods, is shown in Figures 1-2 and 1-3.

A comparison of the wind direction and speed data of the two periods generally showed only slight differences. The only notable differences indicated were in the Detroit area. At the Detroit City Airport, a greater frequency of west winds was accompanied by less frequent northwest and north winds during the investigation period as compared to the longer period.

Differences between the Detroit and Sarnia wind direction frequencies reveal the influence of topography on the winds at the two locations. In the St. Clair River area, channeling appears to occur along the St. Clair River, and Lake Huron exerts an influence on land-lake breezes. These effects produce an increase in the frequency of winds from the north-northeast and south-southwest. The land-lake breezes occur mostly during the spring and summer and show a diurnal cycle, with off-lake winds occurring during the day and off-land winds occurring during the night. The differences in the frequencies of wind directions during the day and night are illustrated by Figure 1-4, which shows the wind roses for the investigation period. The decrease in the frequency of north-northeast winds during the night is striking. By comparison, little difference appeared between the day and night wind roses for the Detroit City Airport.

Figure 1-5 shows the climatological wind roses for all stations used in the study. Although the winds that blow parallel to the St. Clair River predominate, the winds in that area more frequently transport air from the U. S. into Canada than in the reverse direction. Because of the bend in the Detroit River and the north-south, east-west orientation of the International Boundary, the winds in the Detroit - Windsor vicinity blow from one country to the other with almost equal frequency. In the southern portion of this area, however, where the U. S. side of the border is heavily industrialized, the winds blow more frequently from the U. S. into Canada than in the reverse direction, as indicated by the roses for Stations 412, 211, and 410 in Figure 1-5.

Increased wind speeds cause a reduction in pollution concentrations when the pollutants are emitted from near ground level. The difference in the average wind speeds given in Table 1-1 for the Detroit City Airport (about 10 mph) and the Sarnia Tower (8 mph) are due to the differences in the heights at which the sensors were exposed. The Detroit City Airport anemometer is exposed at 81 feet, whereas the Sarnia Tower data given are for an elevation of 20 feet. At the

Table 1-1. FREQUENCY OF WIND DIRECTION AND ANNUAL AVERAGE WIND SPEED FOR SURVEY AND LONGER-TERM CLIMATOLOGICAL PERIODS

Station	Period	Time, %																	Annual average wind speed, mph
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm	
Detroit City Airport	Dec 1967-Nov 1968	6.1	3.0	1.8	3.4	4.3	4.6	4.0	4.0	12.0	4.6	7.8	6.6	13.9	10.0	4.6	4.0	5.1	10.2
	1951-1960	9.9	4.3	4.1	3.8	5.8	3.7	4.6	3.0	9.7	5.3	9.1	5.5	9.1	8.2	8.9	4.3	1.2	10.1
Sarnia Tower, at 20 feet	Dec 1967-Nov 1968	5.3	9.2	2.0	1.9	2.0	3.9	3.3	7.6	10.1	14.4	5.3	7.6	5.8	8.8	5.3	5.3	1.9	8.0
	1965-1968	8.0	8.9	3.0	1.8	2.6	3.3	4.4	5.5	9.5	12.7	7.4	7.0	7.3	6.9	6.4	3.9	1.4	8.0

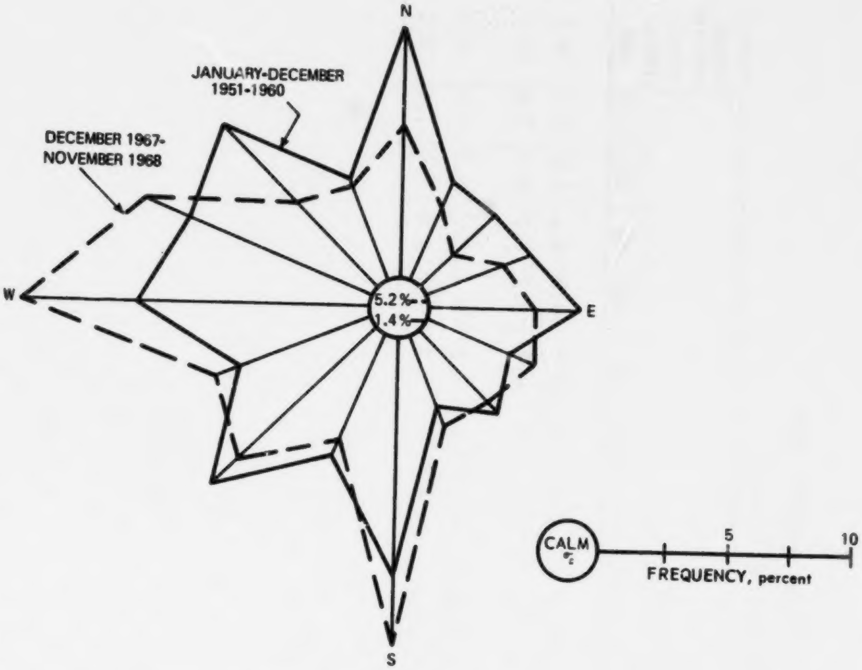


Figure 1-2. Percent frequency of wind directions for survey and long-term periods at Detroit City Airport.

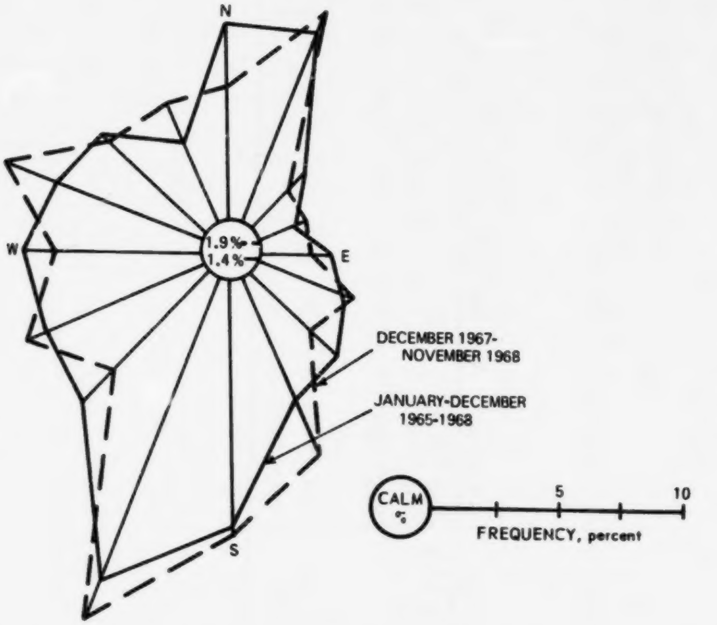


Figure 1-3. Percent frequency of wind directions for survey and long-term periods at Sarnia Tower (20-ft level).

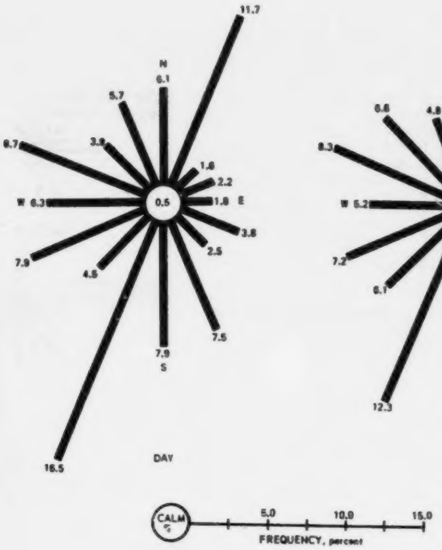


Figure 1-4. Wind roses showing frequency of wind directions for day (0700 to 1800 hrs) and night (1900 to 0600 hrs) at Sarnia tower (20-ft level), December 1967 through November 1968.

200-foot level of the Sarnia Tower, the winds average about 13 mph. The annual average wind speed in the study areas is much the same as the average wind speed across most of the Great Lakes region.

1.2.3.2 Atmospheric Stability - The stability of the lower atmosphere, of which change in temperature with height is an indication, affects the dispersion of air pollutants. The more rapidly the air temperature decreases with height, the more unstable the air becomes. Unstable air enhances vertical dispersion and generally results in lower ground-level pollutant concentrations. A layer in which the temperature increases with height is called an inversion. Inversions inhibit vertical dispersion and dilution of pollutants. Prolonged inversions, such as may occur during atmospheric stagnations of several days, can result in the excessive concentration of air contaminants.

The percentage frequency of inversion occurrences by season and time of day for a tower in northwest Detroit (about 10 miles from downtown) and another south of Sarnia are shown in Tables 1-2 and 1-3. Historical data are given in the tables for both the Sarnia and Detroit data. In addition, Sarnia tower data obtained during the investigation are included. The Detroit tower was not operated during the period of investigation. The data are not strictly comparable since the Detroit records were based on temperature measurements made at 20 and 300 feet above the ground whereas the Sarnia data were from 20 and 200 feet. The difference in the depths of the layers and the height from which temperature measurements were obtained contributes some to the greater frequency of inversions shown for Sarnia. Inversions are usually formed by cooling from below, which favors the

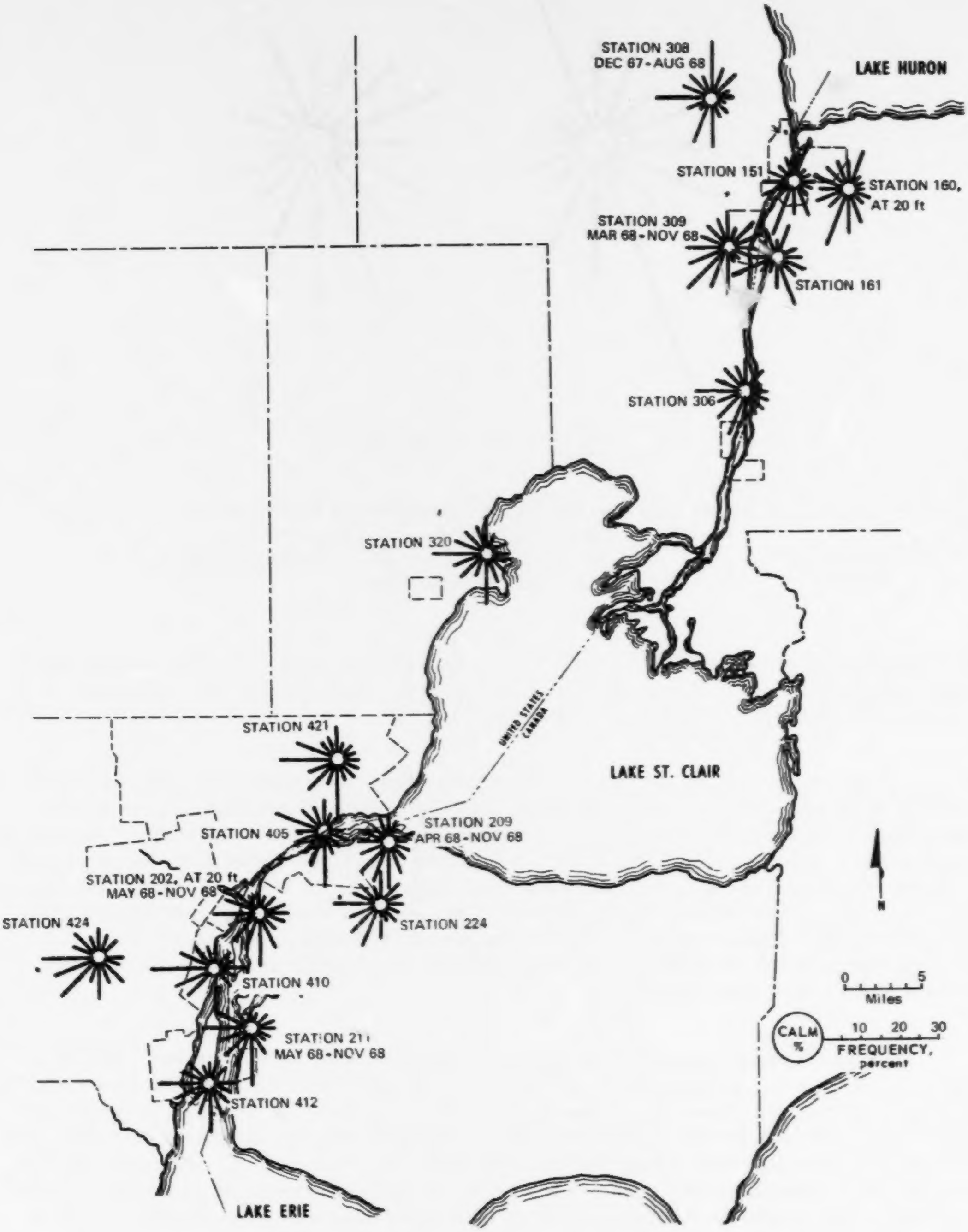

STATION 308
DEC 67-AUG 68
LAKE HURON
STATION 151
STATION 160,
AT 20 ft
STATION 309
MAR 68-NOV 68
STATION 161
STATION 306
STATION 320
UNITED STATES
CANADA
STATION 421
LAKE ST. CLAIR
STATION 405
STATION 209
APR 68-NOV 68
STATION 202, AT 20 ft
MAY 68-NOV 68
STATION 224
STATION 424
STATION 410
STATION 211
MAY 68-NOV 68
STATION 412
LAKE ERIE
N
0
5
Miles
CALM
%
10
20
30
FREQUENCY,
percent

Figure 1-5. Roses of hourly wind direction frequencies for meteorological network stations, December 1967 through November 1968 (unless otherwise indicated).

Table 1-2. FREQUENCY OF OCCURRENCE OF INVERSIONS AT DETROIT AIRPORT TOWER BY TIME OF DAY AND SEASONS, JANUARY THROUGH DECEMBER 1959 AND MARCH 1962 THROUGH FEBRUARY 1963

Time	Hours, %				
	Winter	Spring	Summer	Fall	Annual
00-05	7.8	12.7	19.0	14.5	13.5
06-11	5.9	4.6	6.9	7.6	6.3
12-17	2.2	0.7	1.6	0.8	1.3
18-23	8.0	9.0	11.6	13.0	10.4
Total	23.9	27.0	39.1	35.9	31.5

Table 1-3. FREQUENCY OF OCCURRENCE OF INVERSIONS AT SARNIA TOWER BY TIME OF DAY AND SEASONS FOR INDICATED PERIODS

Period	Time	Hours, %				
		Winter	Spring	Summer	Fall	Annual
Jan 1963 - Dec 1964	00-05	18.9	19.6	23.4	20.6	20.6
	06-11	11.9	5.3	3.7	8.4	7.3
	12-17	6.2	1.9	0.9	3.2	3.1
	18-23	17.1	18.2	19.4	20.6	18.8
	Total	54.1	45.0	47.4	52.8	49.8
Dec 1967 - Nov 1968	00-05	13.3	18.6	21.2	19.4	18.2
	06-11	6.8	6.3	4.8	7.6	6.4
	12-17	4.8	2.1	1.0	3.3	3.9
	18-23	13.7	17.0	18.2	19.2	17.1
	Total	38.6	44.2	45.3	38.6	44.5

creation of shallow inversions. The difference in the height of measurements at the two stations, the different periods of data collection, and the "heat island" effect of urban Detroit all could contribute to the greater frequency of inversions found at Sarnia. The differences in inversion frequency between the earlier period and the period of the investigation were insignificant.

The inversion frequency data indicated that on an annual basis, ground-based inversions occur in the Detroit - Windsor and Port Huron - Sarnia area between 30 and 50 percent of the time. They revealed the expected diurnal variations in frequency related to surface coolness; that is, inversions occur most frequently when temperatures are minimal near sunrise and least frequently when temperatures are maximal in the afternoon. Inversions in the general area occur most frequently in summer and fall, when clouds, precipitation days, and average wind speeds are minimal. Further analysis of the inversion data in relation to winds (summaries not given) showed that few inversions occurred with moderate or strong winds, apparently because of greater mechanical mixing. The Detroit and Sarnia data showed that inversions were frequent when winds were less than 4 mph but rarely occurred when winds were greater than 10 mph. Further, the data for Detroit and Sarnia revealed that inversions occurred most frequently with southerly winds.

Besides variations in the frequency of inversions with time of day, the persistence of inversions is of concern. Inversions that persist for many hours will, of course, tend to cause a greater build up of pollution than those that last only a few hours. The number and percent of inversions persisting for various lengths of time during the investigation period are shown in Table 1-4 for Sarnia tower. The table indicates that few prolonged inversions occurred. Although about half of the cases lasted 12 hours or more, only one percent, or three cases, lasted 24 hours or more.

Table 1-4. PERSISTENCE OF TEMPERATURE INVERSIONS AT SARNIA TOWER BETWEEN 20 AND 200 FEET, DECEMBER 1967 THROUGH NOVEMBER 1968

Inversion duration, consecutive hrs.	Cases[a] of inversion durations ≥ indicated hours	
	Number	Percent
3	244	90
6	195	72
9	167	61
12	140	51
15	39	14
18	9	3
21	5	2
24	3	1
36	1	<1
48	0	0

[a] Total cases = 272.

There is further evidence to indicate that prolonged periods of poor dispersion are infrequent in the area. Numerous studies have shown that the potential for major air pollution episodes is related to incidence of stagnating anticyclones (high pressure areas) with associated inversions that linger a few days. Korshover,[3] in a study examining the weather patterns for the 30-year period, 1936 through 1965, found that stagnating anticyclones lasting 4 days or more occurred in the general vicinity of the study area only 18 times, or on the average of only once every 2 years. In contrast, there were 90 such cases in parts of the Southern

Appalachians during the same period. The greatest number of the stagnating high pressure areas in Eastern North America occurred in October. An examination of weather patterns during the investigation indicated that no lengthy stagnation periods occurred during this period.

1.2.3.3 Other Meteorological Factors

1.2.3.3.1 Sunshine - Photochemical reactions may take place between pollutants to produce compounds more objectionable than the original ones. As sunlight is the energy source for these reactions, the amount of sunshine is an important factor in air pollution studies. Table 1-5 shows the percentage of the hours between sunrise and sunset when direct solar radiation was received at the ground at the Detroit City Airport and at Chatham in Kent County. Some of the differences observed between areas may result from the different types of instruments used and possibly from additional cloudiness at Chatham due to its location relative to Lakes St. Clair and Erie.

Table 1-5. PERCENT OF POSSIBLE HOURS OF SUNSHINE, GIVEN BY MONTH; BASED ON 30-YEAR RECORD AT DETROIT CITY AIRPORT AND 31-YEAR RECORD AT CHATHAM, ONTARIO

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Detroit City Airport	32	43	49	52	59	65	70	65	61	56	35	32	54
Chatham, Ontario	23	33	34	39	47	50	56	56	49	46	29	23	42

1.2.3.3.2 Degree-days - During the heating season, the temperature of the air indirectly affects air pollutant concentrations in an area because of its inverse relationship to the amount of fuel required for space and residential heating. The heating "degree-day" parameter is used as an index of fuel consumption and is computed for each day by subtracting the daily mean temperature from 65 ° F; negative values are considered "zero."

Table 1-6 gives heating degree-days by month for Detroit City Airport, Windsor Airport, Sarnia, and Port Huron. Differences in annual degree-days among them are less than 10 percent. Since the most densely populated areas show the lowest degree-days, part of the differences can be explained by the urban heat island effect.

1.2.3.3.3 Precipitation - Precipitation is an important weather element affecting air pollution because of its washout or scavenging effects on the large particulates suspended in the atmosphere. Rainfall is thus desirable since air is partially cleansed by the coalescence of particles with raindrops.

Precipitation occurs in this area most frequently during the late fall, winter, and spring seasons. Table 1-7 gives by month the normal amounts of precipitation recorded at Windsor Airport, Detroit City Airport, and Port Huron. Table 1-8 gives the average number of days each month that had measurable amounts of precipitation at Windsor Airport and Detroit City Airport during the 10 years, 1951 through 1960.

Table 1-6. CLIMATOLOGICAL AVERAGE; DEGREE-DAYS GIVEN BY MONTH

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Detroit City Airport	1,181	1,058	936	522	220	42	0	0	87	360	738	1,088	6,232
Windsor Airport	1,225	1,096	977	555	251	54	22	16	102	391	768	1,121	6,579
Sarnia	1,243	1,158	1,023	645	353	96	31	34	114	425	774	1,138	7,061
Port Huron	1,200	1,170	950	720	300	90	10	30	120	390	770	1,100	6,851

Table 1-7. NORMAL AMOUNTS OF PRECIPITATION
(in.)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Windsor Airport	2.21	2.22	2.74	3.05	3.53	2.93	2.99	3.15	2.36	2.81	2.41	2.23	32.41
Detroit City Airport	2.05	2.08	2.42	3.00	3.53	2.83	2.82	2.86	2.44	2.63	2.21	2.08	30.95
Port Huron	1.85	1.92	2.14	2.66	3.17	3.44	3.05	3.06	2.66	2.76	2.58	1.96	31.25

Table 1-8. AVERAGE NUMBER OF DAYS WITH PRECIPITATION;
BASED ON PERIOD 1951 THROUGH 1960

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Windsor Airport	14	13	14	12	12	10	10	9	9	9	12	14	138
Detroit City Airport	14	13	13	13	13	11	9	9	9	9	12	13	138

Table 1-9 gives a comparison of the percent of possible hours of sunshine, the number of heating degree-days, the amounts of precipitation, number of days with precipitation during the period studied, and long-term climatic data for the Detroit area. The data indicate that the year studied had 15 percent more hours of possible sunshine than normal. The year studied was somewhat warmer than normal and, correspondingly, the number of heating degree-days was less than normal. Although the precipitation exceeded the normal by 20 percent, there were fewer days with measurable precipitation during the year studied.

Table 1-9. COMPARISON OF ANNUAL METEOROLOGICAL PARAMETERS FOR THE SURVEY PERIOD AND CLIMATOLOGICAL DATA FOR DETROIT CITY AIRPORT

	Survey period	Climatic mean
Possible hours of sunshine, %	69	54
Average temperature, °F	51.4	50.1
Number of heating degree-days	5898	6232
Total precipitation, in.	37.67	30.95
Number of days with precipitation ≧ 0.01 in.	107	138

Data from the investigation of winds, atmospheric stability, and other meteorological factors showed some deviations from the long-term averages or "normals." In general, however, these anomalies were not excessive, so that the year of study may be considered to have had nearly normal meteorological conditions.

1.3 AIR QUALITY SURVEY DESIGN

Because of the different industrial characteristics of the St. Clair and Detroit River areas, the types of pollution problems present also differ. This was apparent from the inspections made by the Board and from the comments made at public hearings conducted in June 1967 in Port Huron and Windsor by the International Joint Commission. Essentially, complaints from the St. Clair River area at the public hearings were from the U.S. side and related to odors from oil refineries and chemical plants on the Canadian side. Complaints from the Detroit River area originated mainly from the Canadian side as the result of particulate emissions from metallurgical industries south of the city of Detroit. In each case, responses from the public to the pollution that crossed the border were almost entirely one-sided, being directed against the Canadian side in Port Huron - Sarnia and against the U.S. side in Detroit - Windsor.

1.3.1 Design Considerations

Sulfur dioxide was generally known to be a significant pollutant in Sarnia as a result of the operation of the oil refineries in the Sarnia area and because of the proximity of the large coal-burning power plant facilities on both sides of the St. Clair River. Odors from sources in Sarnia were a problem in Port Huron and Sarnia, and particulates were a significant problem on both sides of the St. Clair River. When synergistic chemicals such as styrene and halogens reacted, strong lacrimators were formed that, depending on wind direction, had profound effects on the receptor population. For at least 25 years, until corrected in late 1969, emissions from the coal-burning facilities of the Polymer Corporation in Sarnia caused appreciable difficulty in the city of Port Huron across the river.

The same type observations could not be made for Windsor and Detroit, mainly because the character of the industry there is different and the extent of the development of the downriver Detroit area is much more extensive and intense than that in Windsor to date. It was reasonable to expect that residents of the

Windsor area would readily complain about Detroit and downriver Detroit sources because transboundary pollution is obvious. On the other hand, residents of the Detroit and downriver Detroit area have experienced pollution from local sources and perhaps did not complain of any sources on the Windsor side of the river because pollution from those sources was not readily apparent, even though it existed.

The differences in the nature of the industries and the resulting complaints in the two areas were considered in the survey design. In Windsor, Detroit, and environs, the greatest attention was given to particulates. The instrumentation used to measure particulates consisted primarily of dustfall gauges, high-volume samplers for the measurement of total suspended particulates, and filter-tape samplers for the determination of smoke haze or soiling index. Considerable stress was placed upon defining the composition of suspended solid matter, and a substantial number of samples were analyzed for various metals, particularly iron.

Because of the large amount of fuel used in Detroit, SO_2, probably a major transboundary pollutant, was measured. For completeness, rather than for indications of border pollution, NO_x, CO, HC, and oxidants also were measured in the Detroit - Windsor area. Other pollutants, including sulfates, polycyclic HC, sulfuric acid, and fluorides, were measured at some locations.

In the Port Huron - Sarnia region, greater emphasis was placed upon gaseous and volatile pollutants such as HC, hydrogen sulfide (H_2S), NO_x, SO_2, and oxidants. Dustfall, suspended particulates, and soiling index also were measured, but less intensively than in the Detroit - Windsor area. Particulate samples were not subjected to the detailed analyses performed in the Detroit - Windsor study.

Attempts were made to evaluate odor problems by personal reaction, since the substances which cause odors are extremely difficult if not impossible to analyze chemically at the concentrations which occur in the ambient atmosphere, especially since they are usually transient. Details of the techniques used and the observations made are contained in Section 2.

1.3.2 Emissions Inventory

A detailed inventory of all sources of pollution was conducted in each of the two survey areas to identify the relative contributions of different source types and to establish the overall quantitative discharges of the various pollutants. Particulate, SO_x, CO, HC, and NO_x emissions were tabulated on the bases of a detailed questionnaire and engineering estimates made by the source inventory survey group. The information was classified to provide an estimate of the respective quantitative contributions from industrial, governmental, domestic, and vehicular sources.

1.3.3 Meteorological Observations

As a basis for determining the transboundary flow of contaminants and the identification of specific pollution sources, wind direction and speed data were collected at several sites in both of the survey areas. Data were obtained at special stations as well as at those of the weather services and the military.

A secondary purpose of these observations was to provide, in conjunction with the source inventory data, a basis for developing simulation models for the prediction of present pollution levels and future trends. To facilitate this work, temperatures of the lower atmosphere were measured routinely at instrumented towers in Sarnia and Windsor. During special periods of intensive study, pilot-balloon wind measurements and tethered-balloon temperature soundings were made.

In addition, an instrumented aircraft was used during a 2-week period to assess the detailed pattern of pollution in a cross section along the border at times of transboundary flow. Sulfur dioxide and particulates were measured from the aircraft while detailed meteorological observations were being made from the ground.

The meteorological data were used to assess the representativeness of the survey sampling period by comparing them with long-term data available from permanent national meteorological stations and from existing state and provincial air quality stations.

1.3.4 Special Studies on Effects

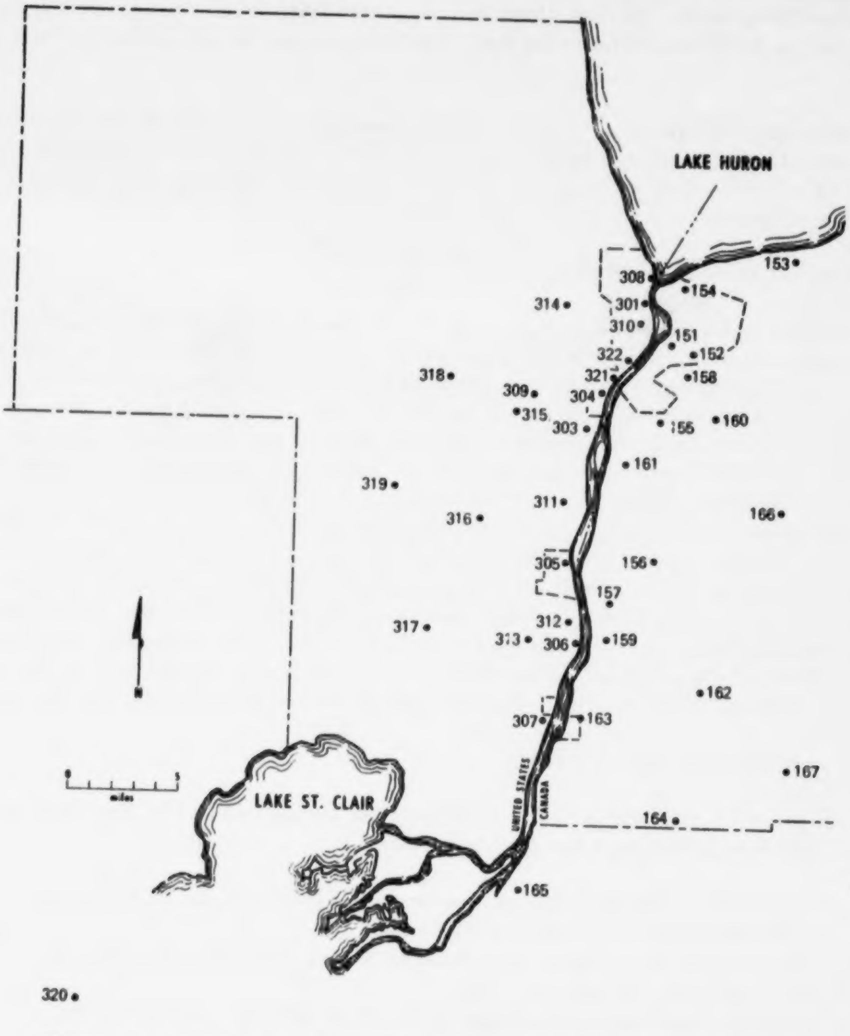
An Effects Committee was formed to advise the Air Pollution board and to make recommendations on the need for and development of studies on health effects or epidemiology. After a review of the levels at which the effects of air pollution on health and welfare could be measured, the populations that were available for study, and the shortcomings of the earlier Windsor - Detroit health survey, the Committee recommended that a series of new studies be undertaken. Arrangements for a public perception study to be conducted in the Windsor and Sarnia areas are well underway. The Board intends to report on this work at a later date. Other special observations were made to assess the effects of pollutants on vegetation and materials. These studies included the examination of existing plants, crops, and gardens, and the exposure of specific plant species to ambient pollutants in special chambers. The influence of pollution on materials was assessed by the exposure to pollution of a variety of materials in the Effects Package routinely used by the U.S. National Air Pollution Control Administration.

1.3.5 Summary of Project Design

The general structure of the 1968 survey as stated in the final project outline included the following separate components:

1. A meteorological study of the two affected regions to delineate any international flow of pollutants;
2. Measurement of the contamination of air masses crossing the international boundary;
3. Identification and evaluation of harmful effects caused by the transboundary flow of air pollution;
4. Identification and quantification of sources of transboundary pollution;
5. Determination of the appropriate control measures and estimation of the costs of implementing them.

The study area contained a final network of 80 aerometric sampling locations. Of these, 53 collected suspended particulate data and 26 monitored for SO_2 concentrations. Almost every station had static devices for the collection of dustfall and sulfation samples. Additional sampling for oxidants, HC, fluorides, and other pollutants was performed at some of the sites. The locations of all International Joint Commission sampling stations are shown in Figure 1-6; a legend of the pollutants sampled for at each location is given in Table 1-10.


LAKE HURON
153
308
154
314
301
310
151
322
152
321
158
318
309
304
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303
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319
311
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305
156
157
312
317
313
306
159
162
307
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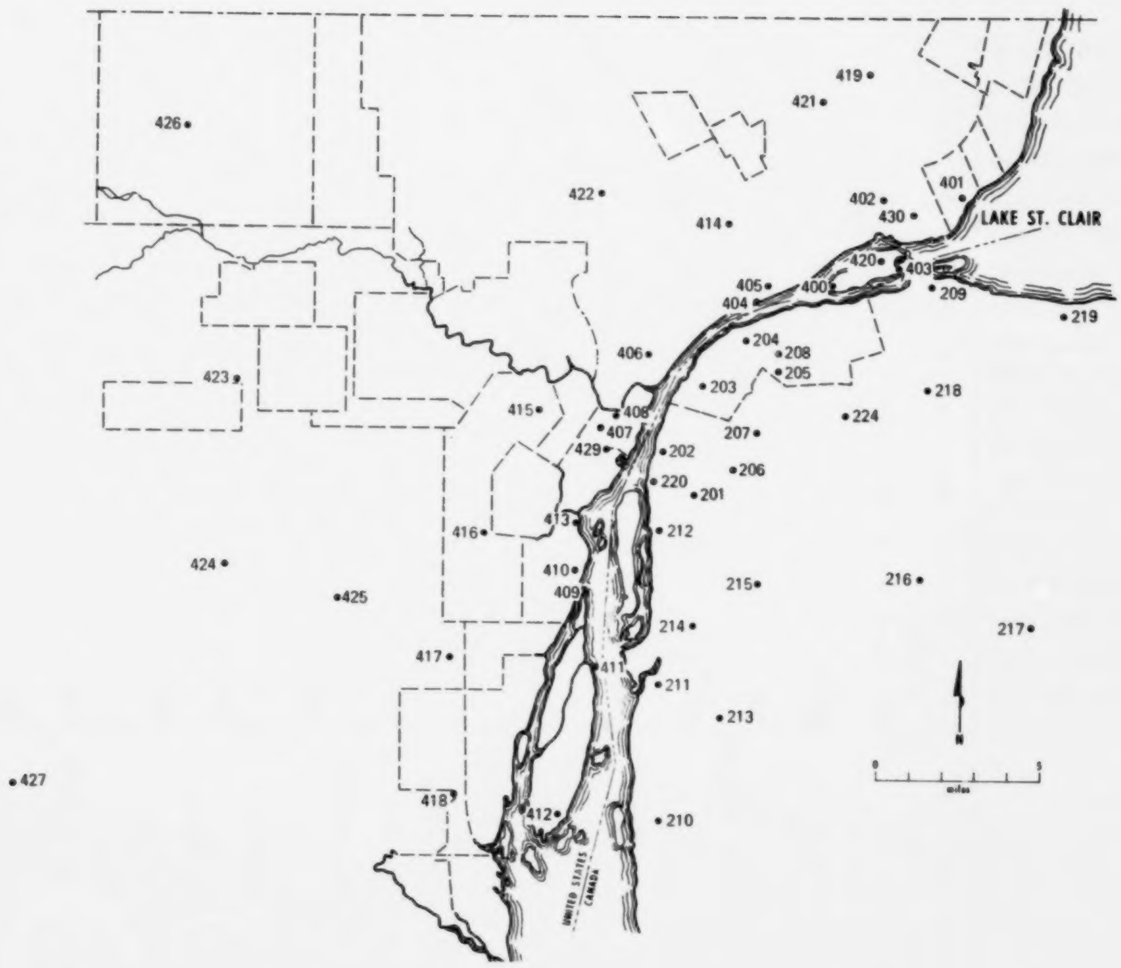
miles
LAKE ST. CLAIR
UNITED STATES
CANADA
164
165
320

Figure 1-6. Locations of International Joint Commission sampling stations.


LAKE ST. CLAIR
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409
215
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425
214
217
417
411
211
213
N
0
5
miles
427
418
412
210
UNITED STATES
CANADA

Figure 1-6 (continued). Locations of International Joint Commission sampling stations.

Table 1-10. LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	Sticky paper	Hydrogen sulfide	Fluoride ion (F⁻)	Plant shelter
151	Foot of Lochiel St. Sarnia, Ontario	ORF[a]	x	x		x	x		x	x	x	x		x		x		
152	East St. Sarnia, Ontario	ORF	x	x		x	x		x		x	x		x				
153	Sarnia Airport Sarnia, Ontario	ORF					x				x	x						
154	Sarnia Yacht Club Point Edward, Ontario	ORF					x				x	x	x					
155	Lambton College Sarnia, Ontario	ORF	x	x		x	x		x	x	x	x				x		
156	Moore and Township Rds. # 6 Sarnia, Ontario	ORF	x				x		x	x	x	x						
157	Lambton Generating Plant Courtwright, Ontario	ORF	x						x	x		x						
158	Tecumseh Park Sarnia, Ontario	ORF	x	x		x	x		x	x	x	x	x			x		x
159	C.I.L. Plant and Highway 40 Courtwright, Ontario	ORF					x				x	x						
160	Churchill and McGregor Rds. Sarnia, Ontario	ORF					x		x	x	x	x						
161	Colborne S.E. Corunna, Ontario	ORF	x	x			x		x	x	x	x				x		
162	Lambton County, Rd. # 2 Sombra, Ontario	ORF									x	x						
163	Ontario Police Post Sombra, Ontario	ORF	x	x			x		x	x	x	x						
164	Sombra Township Rd. Sombra, Ontario	ORF									x	x						
165	Lambton Count Rd. # 1 Port Lambton, Ontario	ORF									x	x						

Table 1-10 (continued). LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	Sticky paper	Hydrogen sulfide	Fluoride ion (F⁻)	Plant shelter
166	Confederation St. 3 miles east of Modeland Rd. Sarnia, Ontario	ORF									x	x						
167	Sombra Concession Rd. Sombra, Ontario	ORF									x	x						
201	690 Highway 18 Windsor, Ontario	DNHW					x		x		x	x						
202	Morton Dock Terminal Windsor, Ontario	DNHW	x				x		x	x	x	x	x	x	x	x	x	
203	3822 Sandwich St., W. Windsor, Ontario	DNHW					x		x		x	x			x			
204	Windsor City Hall Windsor, Ontario	DNHW					x	x										
205	1250 Langlois Ave. Windsor, Ontario	DNHW					x		x		x	x						
206	3631 Huron Line Rd. Windsor, Ontario	DNHW					x		x		x	x						
207	3120 Dougall Ave. Windsor, Ontario	DNHW					x		x		x	x			x			
208	471 University Ave., W. Windsor, Ontario	DNHW	x	x	x									x				
209	Windsor - Tecumseh Waterworks Windsor, Ontario	DNHW					x		x	x	x	x						
210	Amherstburg Post Office Amherstburg, Ontario	DNHW									x	x						
211	Benetau Farm, R.R. # 2 River Canard, Ontario	DNHW	x				x		x	x	x	x			x			
212	Library St. - Old Front Rd. Windsor, Ontario	DNHW	x				x		x		x	x			x	x		

Table 1-10 (continued). LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	Sticky paper	Hydrogen sulfide	Fluoride ion (F$^-$)	Plant shelter
213	Vollan Farm R.R. # 4, Amherstburg, Ontario	DNHW									x	x						
214	938 Martin Lane River Canard, Ontario	DNHW									x	x						
215	Peck Farm Disputed Rd. River Canard, Ontario	DNHW					x		x		x	x			x			
216	Highway 3, four miles N.W. Highway 114 Windsor, Ontario	DNHW									x	x						
217	Malden Rd. at Highways 3 and 114 Sandwich South, Ontario	DNHW					x		x		x	x	x					
218	5715 E. C. Row Ave. Windsor, Ontario	DNHW									x	x			x			
219	3933 Lesperance Rd. Tecumseh, Ontario	DNHW									x	x						
220	Canadian Rock Salt Co. Windsor, Ontario	DNHW	x				x		x		x	x						
224	Walker Airport Windsor, Ontario	DNHW								x								
225	495 Crawford Ave. Windsor, Ontario	DNHW																x
301	Water Filtration Plant Port Huron, Mich.	PHS					x		x				x					
303	Water Treatment Plant Marysville, Mich.	PHS	x				x		x		x	x			x	x		
304	Public Service Garage Marysville, Mich.	PHS								x								
305	State Police Post St. Clair, Mich.	PHS	x				x						x				x	
306	Detroit Edison St. Clair, Mich.	PHS								x								

Table 1-10 (continued). LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	Sticky paper	Hydrogen sulfide	Fluoride ion (F⁻)	Plant shelter
307	Holy Cross High School Marine City, Mich.	PHS					x				x	x			x		x	
308	U.S. Coast Guard Station Port Huron, Mich.	PHS								x	x	x						
309	4836 Gratiot St. Marysville, Mich.	PHS								x								
310	Sperry Dept. Store Port Huron, Mich.	PHS	x				x		x		x	x			x	x		
311	Yankee - River Rds. St. Clair Township, Mich.	PHS									x	x						
312	S.E. of Remer - Clark E. China Township, Mich.	PHS									x	x						
313	Belle River - King Rds. E. China Township, Mich.	PHS									x	x						
314	Michigamme Sch. Port Huron, Mich.	PHS					x				x	x						
315	Bartlett Road Kimball Township, Mich.	PHS									x	x						
316	Mitchell Road - Rattle Run St. Clair Township, Mich.	PHS					x				x	x						
317	Meisner and McKinley China Township, Mich.	PHS									x	x						
318	Richman Road - Dove St. Kimball Township, Mich.	PHS									x	x						
319	Gratiot Rd. - Palms Columbus Township, Mich.	PHS					x				x	x						
320	Selfridge AFB, Mich.	USAF								x								

Table 1-10 (continued). LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	STicky paper	Hydrogen sulfide	Fluoride ion (F^-)	Plant shelter
321	2750 Military Ave. Port Huron, Mich.	PHS		x														x
322	2445 Military Port Huron, Mich.	PHS				x												
400	West end of Belle Isle Detroit, Mich.	PHS					x				x	x			x			
401	Three Mile Park Grosse Point Park, Mich.	PHS					x				x	x			x			
402	1660 Hillger Detroit, Mich.	PHS DET					x				x	x						
403	Coast Guard Station, Belle Isle Detroit, Mich.	PHS DET	x				x		x		x	x			x			
404	Veterans Memorial Building Detroit, Mich.	PHS DET	x				x		x		x	x			x			
405	City - County Building Detroit, Mich.	PHS								x								
406	7420 West Fort St. Detroit, Mich.	PHS					x		x		x	x						
407	River Rouge High School River Rouge, Mich.	PHS					x				x	x						
408	Anchor and Burke River Rouge, Mich.	WC	x		x	x										x		
409	Hennepin Point Grosse Ile, Mich.	PHS					x	x			x	x	x			x		
410	Wyandotte Chemicals, South Plant Wyandotte, Mich.	PHS								x								
411	19505 Lighthouse Point Grosse Ile, Mich.	PHS	x	x			x		x		x	x			x		x	x
412	Naval Air Station Grosse Ile, Mich.	PHS	x				x		x		x	x			x			
413	87 Biddle Ave. Wyandotte, Mich.	PHS									x	x			x			
414	5201 Woodward Detroit, Mich.	PHS					x				x	x						

Table 1-10 (continued). LEGEND OF SAMPLING OPERATIONS AT LOCATIONS GIVEN IN FIGURE 1-6

Station number	Station location	Service agency	Sulfur dioxide	Total oxidant	Carbon monoxide	Hydrocarbons	Suspended particulates	Respirable dust	Soiling	Meteorological equipment	Dustfall	Sulfation candle	Effects package	Nitrogen oxides	Sticky paper	Hydrogen sulfide	Fluoride ion (F⁻)	Plant shelter
415	Julian Strong Jr. High School Melvindale, Mich.	PHS	x				x				x	x						
416	14700 Moran Allen Park, Mich.	PHS WC	x				x	x			x	x						
417	19366 Allen Rd. Riverview, Mich.	PHS WC					x				x	x						
418	South Rd. School Woodhaven, Mich.	PHS WC					x	x			x	x						
419	12985 Houston-Whittier Detroit, Mich.	PHS DET	x				x		x		x	x						
420	Conservatory Workshop Belle Isle, Mich.	PHS		x													x	x
421	Detroit City Airport Detroit, Mich.	PHS								x								
422	10750 Grand River Detroit, Mich.	PHS					x				x	x						
423	Wayne County Hospital Eloise, Mich.	WC	x				x				x	x						
424	Detroit Met. Airport Romulus, Mich.	PHS								x								
425	Eurekadale Elem. School Taylor, Mich.	PHS					x				x	x						
426	Bently High School Livonia, Mich.	LIV					x						x					
427	Bessie Hoffman Jr. High School Sumpter Township, Mich.	PHS WC					x		x		x	x	x					
429	Ann Visger School River Rouge, Mich.	WC											x					
430	1115 Coplin Detroit, Mich.	DET	x						x									

[a] Service agencies are abbreviated as follows:

ORF - Ontario Research Foundation.
DNHW - Department of National Health and Welfare - Canada.
PHS - United States Public Health Service.
USAF - United States Air Force.
DET - City of Detroit.
WC - Wayne County.
LIV - City of Livonia.

1.4 REFERENCES FOR SECTION 1

1. Report of the International Joint Commission, United States and Canada, on the Pollution of the Atmosphere in the Detroit River Area. International Joint Commission. Washington, D.C., and Ottawa, Ontario, Canada, 1960.

2. Munn, R. E., D. A. Thomas, and A. F. W. Cole. A Study of Suspended Particulate and Iron Concentrations in Windsor, Canada. Atmospheric Environ. 3(1), January 1969.

3. Korshover, J. Climatology of Stagnating Anticyclones East of Rocky Mountains, 1936-1965. U. S. DHEW, EHS, Public Health Service. Publication No. 999-AP-34, 1967.

2. AIR QUALITY OF THE PORT HURON–SARNIA AND DETROIT–WINDSOR AREAS

The significance of measured concentrations of pollutants in the ambient atmosphere must be judged in relation to established air quality standards based on criteria that establish the deleterious effects of the pollutants. The air quality standards considered by the Board to be applicable in the Port Huron - Sarnia and Detroit - Windsor areas are those presently in use in the Province of Ontario and those proposed by the State of Michigan. Throughout this section measured pollutant concentrations are presented in relation to those air quality standards.

In the U. S., the National Air Pollution Control Administration designated on December 9, 1969, in accordance with the Air Quality Act of 1967, a Metropolitan Detroit - Port Huron Intrastate Air Quality Control Region which includes Wayne, Oakland, Macomb, and St. Clair Counties. These same counties make up the International Joint Commission study area on the U. S. side of the St. Clair and Detroit Rivers. The Governor of Michigan has already indicated in a letter to the National Air Pollution Control Administration that it is the intent of the State of Michigan to adopt standards for sulfur dioxide and suspended particulate matter in accordance with the provisions of the Air Quality Act of 1967 on the basis of ambient air quality criteria already promulgated. When specific state standards are adopted, they will be equal to or somewhat higher than the Federal criteria establishing health effect levels For the sake of discussion in this report the ambient air quality standards submitted by Michigan to the National Air Pollution Control Administration will be referred to as the standards to be used by the Michigan Department of Health and local agencies in the implementation of their air pollution control program. The ambient air quality standards for particulate matter and sulfur dioxide are: particulate matter concentrations >70 $\mu g/m^3$, annual geometric mean; and sulfur dioxide concentrations >100 $\mu g/m^3$ (0. 035 ppm), annual mean.

The Province of Ontario proclaimed air quality standards under the Air Pollution Control Act of 1967. These require industries and other sources in the province to achieve controls sufficient to maintain concentrations below certain levels as shown in Table 2-1.

The considerations which appeared to be relevant in the adoption of standards for the assessment of pollution in the two survey areas of the present study are discussed separately in the following sections.

2.1 SUSPENDED PARTICULATES

The transport of particulate material is the most obvious aspect of the transboundary pollution problem in the Detroit - Windsor area. From visual observations

Table 2-1. ONTARIO AIR QUALITY STANDARDS

Pollutant	Sample period	Concentration
SO_2	1-hr avg 24-hr avg annual avg	0.25 ppm 0.10 ppm 0.02 ppm
Suspended particulate	annual geometric mean	60 μg/m^3
Dustfall	30 days annual monthly avg	20 tons/mi^2 13 tons/mi^2
Soiling index	annual geometric mean	0.45 Coh/1000 ft
Sulfation	30 days	0.4 mg/100 cm^2-day
Oxidants	1-hr avg 24-hr avg	0.15 ppm 0.10 ppm
Nitrogen oxides	1-hr avg 24-hr avg	0.20 ppm 0.10 ppm
Fluorides in air	24-hr avg	1.0 ppb
Carbon monoxide	1-hr avg 8-hr avg	60 ppm 15 ppm

and a knowledge of the industries present, it is realistic to acknowledge that particulates are emitted into the atmosphere and are transported across the border by the winds. The purpose of the 1968 survey was to determine whether the quantities of particulates flowing across the boundary were sufficient to produce ambient pollution in excess of reasonable criteria in the other country.

The significance of particulate concentrations has been investigated extensively, and certain criteria have been recommended for some particulates. A review of existing knowledge was published in January 1969 by the U. S. National Air Pollution Control Administration. [1]

In urban areas of the U. S., typical annual total particulate concentrations range from 60 to 200 μg/m^3, although concentrations in many cities fall outside this range. Standards adopted in the U. S. cover a wide range extending from about 50 to 150 μg/m^3 for periods varying from 12 months to 24 hours, respectively.

Information on the suspended-particulate standards for the Province of Ontario and the State of Michigan is presented in the introduction to this section.

Particulate concentrations which appear to be of least significance from a health aspect also appear to represent the minimum threshold for other adverse effects, including the restriction of visibility and the accelerated corrosion of metals. The properties of the particulate material, including composition and particle size, are important in assessing such effects as reduced visibility and damage to materials and vegetation. Particulate materials that are measured as soiling index are mainly of submicron size and make up the fraction which affects visibility the most. The index, normally expressed in Coh/1000 lineal feet (Coh = coefficient of haze), which are units based on optical density, is obtained by measuring the light transmitted through the stains produced on filter paper. It is greatly influenced by the composition of particulates. Carbon particles in combustion products are the chief cause of the stains produced on the paper. Their main consequences are the production of haze and the soiling of buildings.

Few if any publications have shown a connection between soiling index and health effects, although there is probably a strong correlation between this index and the British method of determining mass concentrations. Most air pollution workers agree with an arbitrary scale of values which indicates responses to different smoke haze levels as follows:

Subjective reaction	Coh/1000 lineal feet
Light haze	0 - 1
Moderate smoke haze	1 - 2
Heavy smoke haze	2 - 3
Very heavy haze	3 - 4
Extreme	Above 4

The Ontario standards for soiling index were presented in the introduction to this section.

Some of the suspended particulate samples from the Detroit - Windsor area were analyzed for the presence of specific metals which would be expected to exist as oxides or other compounds. The findings were not intended to provide an assessment of health effects, since concentrations of metals found even in heavily polluted air have not yet been implicated as causing any disease. Not even lead, though well known to be toxic in certain concentrations, is presently considered capable of causing ill effects at the concentrations occurring in ambient air. Metal concentrations have been measured in a number of cities in the U.S. A guide to the significance of metallic-compound particulate pollution in the study area can be found by comparing measured concentrations with the average values in Table 2-2 found in U.S. cities.

Table 2-2. AVERAGE CONCENTRATIONS OF METALLIC-COMPOUND PARTICULATES IN THE UNITED STATES
($\mu g/m^3$)

Metal	Concentration	Metal	Concentration	Metal	Concentration
Antimony	<0.04	Copper	0.09	Nickel	0.034
Beryllium	<0.0002	Iron	1.6	Tin	0.02
Bismuth	<0.001	Lead	0.79	Titanium	0.04
Cadmium	<0.011	Manganese	0.11	Vanadium	0.05
Chromium	0.015	Molybdenum	<0.003	Zinc	0.67
Cobalt	<0.006				

Benzo(a)pyrene is one of the polycyclic hydrocarbons normally associated with carbonaceous solids in the atmosphere. These compounds arise principally from the incomplete combustion of fuels in furnaces. Although liquid fuels contribute some of the polycyclic hydrocarbons in air, coal burning produces most of them. Motor vehicles are sources of some of these compounds but are not considered responsible for more than 20 percent of the total which may occur in most atmospheres.

Polycyclic hydrocarbons are of interest chiefly because of their carcinogenicity. Numerous tests have demonstrated their capacity to produce skin and other forms of cancer in experimental animals. Therefore, by inference, they are suspected as possible contributors to the increasing incidence of lung cancer in humans. Because no direct evidence of this has been found, no criteria or standards have been applied. The samples were analyzed for benzo(a)pyrene because of public health significance. The possibility of relating the occurrence of benzo(a)pyrene to specific pollution sources was not considered likely.

Fluorides in the atmosphere, either as gaseous hydrogen fluoride or as particulate metallic salts, have been associated with damage to vegetation and toxic effects in livestock. Some plant species are particularly sensitive to fluorides, especially gaseous fluoride compounds, and can be damaged by concentrations on the order of one part per billion (ppb). Ingestion by livestock of forage on which particulate fluorides have been deposited, or of forage which has assimilated and accumulated fluorides, results in the accumulation of fluorides in the bones and teeth (fluorosis). Symptoms of fluorosis in livestock are decreased milk production in dairy cattle, loss of weight, stiff posture, lameness, and rough hair coats. Most attempts to associate the symptoms of fluorosis in livestock with air pollution have involved cases occurring in locations near sources such as superphosphate plants and aluminum smelters.

Fluorides are ubiquitous in the atmosphere because they exist in most rocks and soils. Small concentrations occur in most collected particulate samples, but the possibility existed that concentrations in Windsor and Detroit might be higher than the usual background levels because fluorides are sometimes employed in steel processes as fluxes.

Although humans are more tolerant of fluorides than plants and foraging animals are, air quality criteria are normally established on the basis of potential effects on plants and animals. Because of the sensitivity of plants, standards suggested are usually on the order of a few parts per billion.

2.1.1 Air Quality Criteria

In North America and some other parts of the world, suspended particulates normally are measured as 24-hour samples collected by filtration. The particulates thus collected include some of every size occurring at the sampler in a day, with the possible exception of large particles which settle too rapidly to be deflected into the shelter used for these instruments; this fraction is not likely to be appreciable. The normal volume of air passed through the filter in the collection of a sample is about 2,000 cubic meters and results are expressed as micrograms per cubic meter ($\mu g/m^3$).

Samples are collected in Great Britain by a completely different technique, although the results are expressed in the same way. The method employed there and in many parts of Europe involves collecting a sample from an air volume of about 1.5 m^3 and then determining the mass concentration by computation from a calibration based upon a reflectance measurement of the filter-paper stain. This probably yields a result only roughly comparable to that obtained by the high-volume sampler method. The distinction is important because much of the work on the health effects of pollution has been done in Great Britain.

The effects of particulates on health are difficult to assess. The influence of particulates on associated pollutants is believed to be significant, especially in the case of sulfur dioxide and other irritant gases, whose effects tend to be emphasized or synergized by certain particulates. Surface absorption of irritant gases by solid particles is also considered significant and, therefore, the characteristics of the particles are important. In most of the cases described in the literature in which adverse health effects have been attributed to particulates, sulfur dioxide was involved as well.

An air quality criteria document[2] published by the U.S. National Air Pollution Control Administration presents information from various British sources indicating a variety of effects from mixtures of particulates and sulfur dioxide. Thus, the combination of a particulate concentration of 750 $\mu g/m^3$ with about 0.25 ppm of sulfur dioxide (24-hour mean) may result in deaths and a considerable increase in illnesses.

Increases in diseases like chronic bronchitis have been observed with lower concentrations of both sulfur dioxide and particulates. American data have been presented which indicate that increased death rates in persons over 50 years of age could result in areas where the annual geometric mean concentrations of particulates were as low as 80 to 100 $\mu g/m^3$ and sulfur dioxide was present in an amount equivalent to sulfation rates of 30 $mg/100\ cm^2$-month.

2.1.2 Measured Air Quality

2.1.2.1 High-Volume Samplers - The concentrations of suspended particulates were measured using high-volume samplers with glass fiber filters. Each sample was for a 24-hour period starting at midnight. At most stations, one sample was taken every 3 days, although a few stations collected two samples during each 3-day interval. Results were expressed as micrograms of particulates per cubic meter of sampled air ($\mu g/m^3$).

2.1.2.1.1 Port Huron - Sarnia area. Twenty-two sampling stations were located in the vicinity of Port Huron - Sarnia and southward along the St. Clair River. A statistical summary on an annual basis for each of these stations is given in Table 2-3. In addition to average values (arithmetic means), the concentrations at each station that were exceeded by specified percentages of the samples are given. Figure 2-1 is a map of the distribution of average concentrations.

Table 2-4 presents on an annual basis the percentage of samples with concentrations exceeding specified values. Table 2-5 gives by station the percentage of samples in specified concentration ranges.

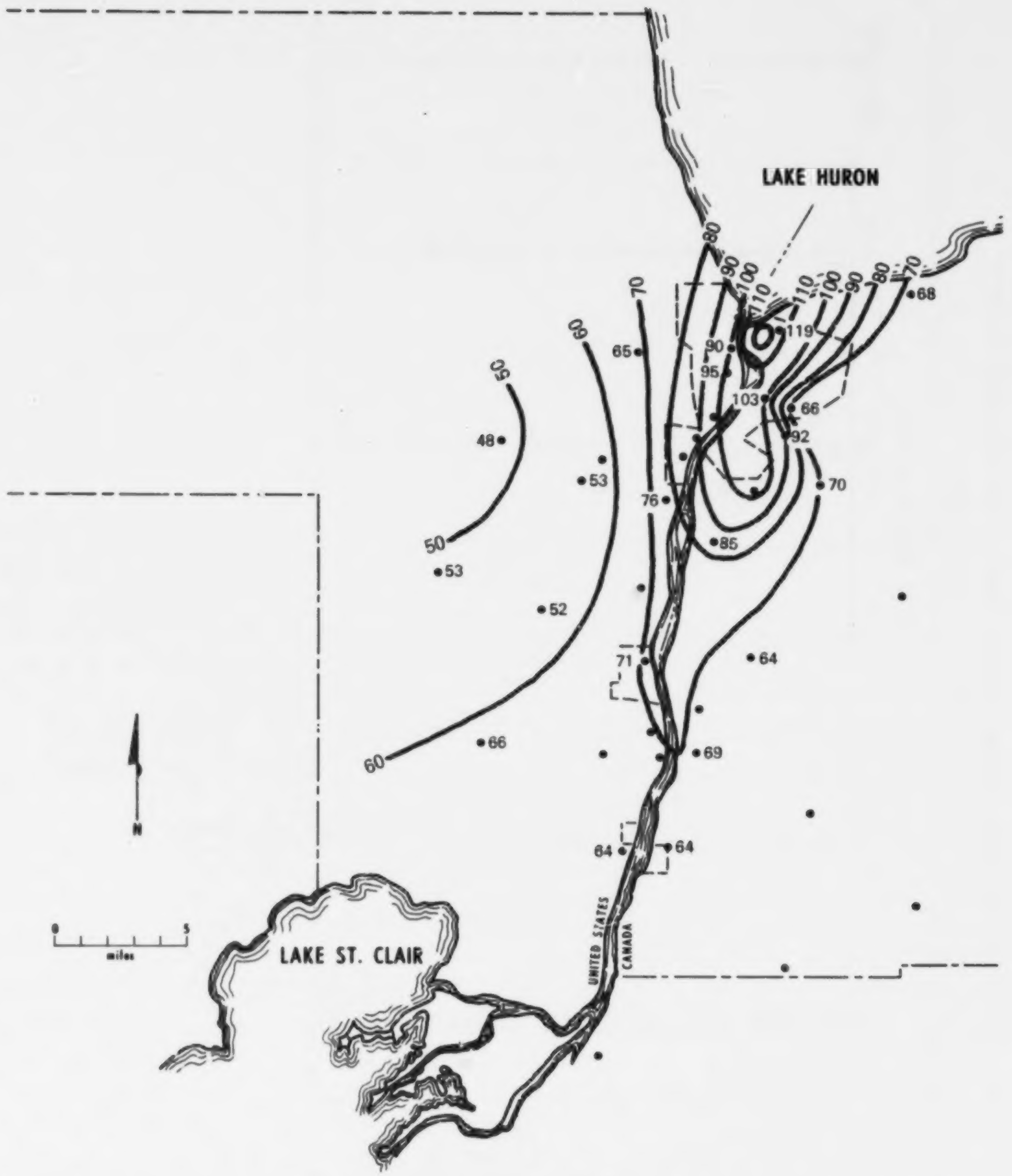
Only 13 of the 22 stations obtained data during each quarter of the year. Seven of the stations had their maximum seasonal average concentration in summer, but in general the differences between seasonal averages were small and, moreover, were not tested for statistical significance.

Table 2-3. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF AVERAGE DAILY SUSPENDED-PARTICULATE CONCENTRATIONS, PORT HURON - SARNIA AREA

Station number	Number of observations	Suspended-particulate concentrations, $\mu g/m^3$									
		% of samples $\geq$ stated value[a]						Maximum observed value	Arithmetic mean	Arithmetic standard deviation	Geometric mean
		90	75	50	25	10	1				
151	96	38	56	97	138	181	240[b]	240	103	52	89
152	20	30	42	60	87	110	145	145	66	32	58
153	84	19	31	57	91	127	273[b]	273	68	48	52
154	95	42	72	110	156	215	300[b]	300	119	64	99
155	79	60	69	94	116	161	261[b]	261	101	42	94
156	83	24	36	61	85	112	166[b]	166	64	33	54
158	95	37	58	87	120	148	244[b]	224	92	44	80
159	87	25	41	62	87	119	213[b]	213	69	39	59
160	96	29	43	68	85	119	165[b]	165	70	33	61
161	87	37	56	75	107	144	280[b]	280	85	48	73
163	80	28	38	61	80	98	161[b]	161	64	30	57
301	209	39	54	78	120	162	248	298	91	49	80
303	221	28	40	64	97	145	237	280	76	48	63
305	224	31	44	64	88	118	188	216	71	36	62
307	221	30	41	61	82	100	144	179	64	29	57
310	188	42	59	81	125	163	282	305	95	53	83
314	89	24	32	58	84	119	204[b]	204	65	39	54
315	50	17	26	45	74	98	156[b]	156	53	32	42
316	102	17	24	51	72	90	155	160	52	32	42
317	36	18	30	60	92	126	180[b]	180	66	43	49
318	52	16	23	43	75	88	105[b]	105	48	27	39
319	96	14	24	45	78	97	157[b]	157	53	35	41

[a] Percentage of samples with observed concentrations equal to or greater than those shown.

[b] Maximum observed value used when less than 100 observations were available.


LAKE HURON
80
90
100
110
110
100
90
80
70
68
70
60
65
119
90
95
50
103
66
48
92
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70
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85
53
52
71
64
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69
64
64
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 2-1. Annual average suspended particulate concentrations (μg/m^3) in Port Huron - Sarnia area.

Graphic presentations of data from Table 2-3 and Figure 2-2 show clearly that most portions of the region have concentrations that exceed the standards set by the Province of Ontario. Figure 2-3 shows that only a few stations exceed the proposed Michigan standard for suspended particulates.

2.1.2.1.2 Detroit - Windsor area. Thirty-four particulate sampling stations operated in the Detroit - Windsor area. Statistical data are given in

Table 2-4. PERCENTAGE OF SUSPENDED-PARTICULATE SAMPLES THAT EXCEEDED SPECIFIC CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	% of samples exceeding stated values:						
	65 μg/m^3	75 μg/m^3	100 μg/m^3	125 μg/m^3	150 μg/m^3	175 μg/m^3	200 μg
151	72	65	47	32	20	14	6
152	43	33	15	7	0	0	0
153	43	35	20	11	6	4	1
154	80	74	58	44	31	19	13
155	84	73	45	25	12	9	3
156	45	36	17	7	2	0	0
158	69	61	40	22	8	5	1
159	47	37	19	8	3	2	1
160	53	41	20	7	2	0	0
161	66	56	34	17	7	6	1
163	44	32	11	2	1	0	0
301	63	54	36	23	13	7	4
303	48	40	25	15	8	5	3
305	47	37	19	9	4	2	1
307	45	33	12	4	1	0	0
310	66	56	37	25	16	9	6
314	37	29	16	9	5	2	2
315	31	23	10	4	2	0	0
316	27	19	8	3	0	0	0
317	44	36	20	10	4	3	0
318	31	23	6	0	0	0	0
319	31	23	10	4	1	0	0

Table 2-5. PERCENTAGE OF SUSPENDED-PARTICULATE SAMPLES WITHIN SELECTED CONCENTRATION RANGES IN PORT HURON - SARNIA AREA

Station number	% of samples within stated ranges:						
	<65 μg/m3	65-75 μg/m3	75-100 μg/m3	100-125 μg/m3	125-150 μg/m3	150-200 μg/m3	>200 μg/m3
151	28	7	18	15	12	14	6
152	57	10	18	8	7	0	0
153	57	8	15	9	5	5	1
154	20	6	16	14	13	18	13
155	16	11	28	20	13	9	3
156	55	9	19	10	5	2	0
158	31	8	21	18	14	7	1
159	53	10	18	11	5	2	1
160	47	12	21	13	5	2	0
161	34	10	22	17	10	6	1
163	56	12	21	9	1	1	0
301	37	9	18	13	10	9	4
303	52	8	15	10	7	5	3
305	53	10	18	10	5	3	1
307	55	12	21	8	3	1	0
310	34	10	19	12	9	10	6
314	63	8	13	7	4	3	2
315	69	8	13	6	2	2	0
316	73	8	11	5	3	0	0
317	56	8	16	10	6	4	0
318	69	8	17	6	0	0	0
319	69	8	13	6	3	1	0

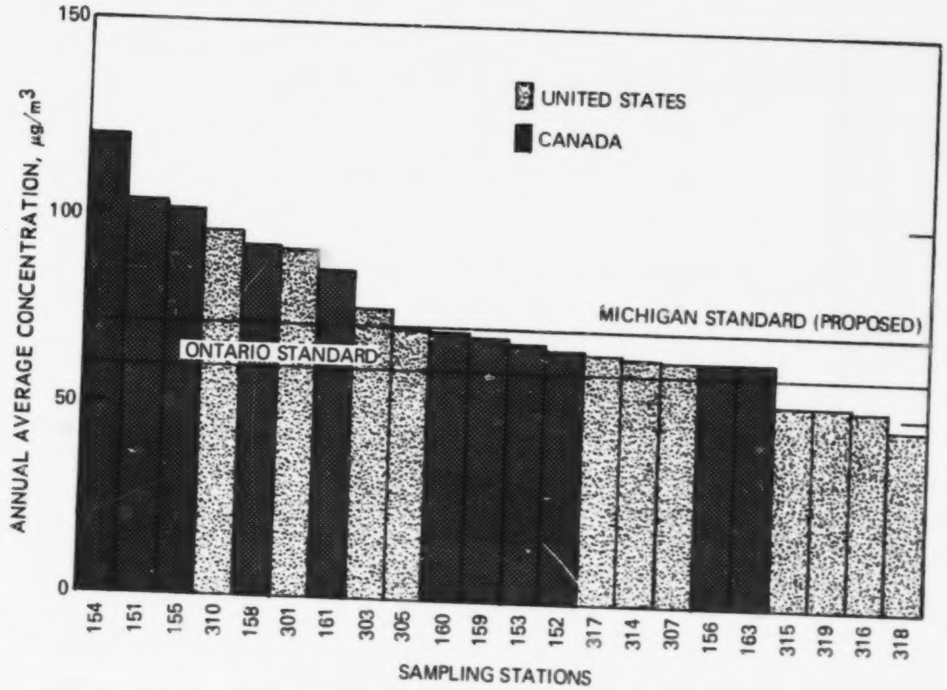

Figure 2-2. Annual average particulate concentrations in Port Huron - Sarnia area.

Tables 2-6 through 2-8. Twenty-five of the stations collected data in each of the four seasons of the year; seasonal average values are given in Table 2-9. The highest average concentrations occurred at more stations during winter and spring than during any other two seasons. The largest number (11) of maximum average values occurred during winter.

A comparison of the air quality in the Detroit – Windsor area with the Ontario Air Quality Standards and the proposed Michigan standard is shown in Figure 2-3. As apparent from the charts, all stations except 427 exceeded both the Ontario standard for annual average concentrations. Thirty-one of the 34 stations exceeded the proposed Michigan standards for suspended particulates.

2.1.2.2 Suspended Particulates - Soiling Index - Soiling index was measured using sequential filter-paper-tape samplers. Two-hour samples were collected and data were reported as Coh per 1,000 lineal feet.

2.1.2.2.1 Port Huron - Sarnia area. Samples were collected at 12 stations in the Port Huron - Sarnia area. Results are summarized in Table 2-10 and Figure 2-4. The only two stations having annual geometric mean Coh values exceeding the Ontario Air Quality Standard are in commercial zones; their annual mean values are 0.6 and 0.5 Coh per 1,000 lineal feet.

2.1.2.2.2 Detroit – Windsor area. In the Detroit – Windsor area, 21 stations measured soiling index. Their annual geometric mean Coh values, arrayed in descending order, are shown graphically in Figure 2-5. Stations 206, 204, 406,

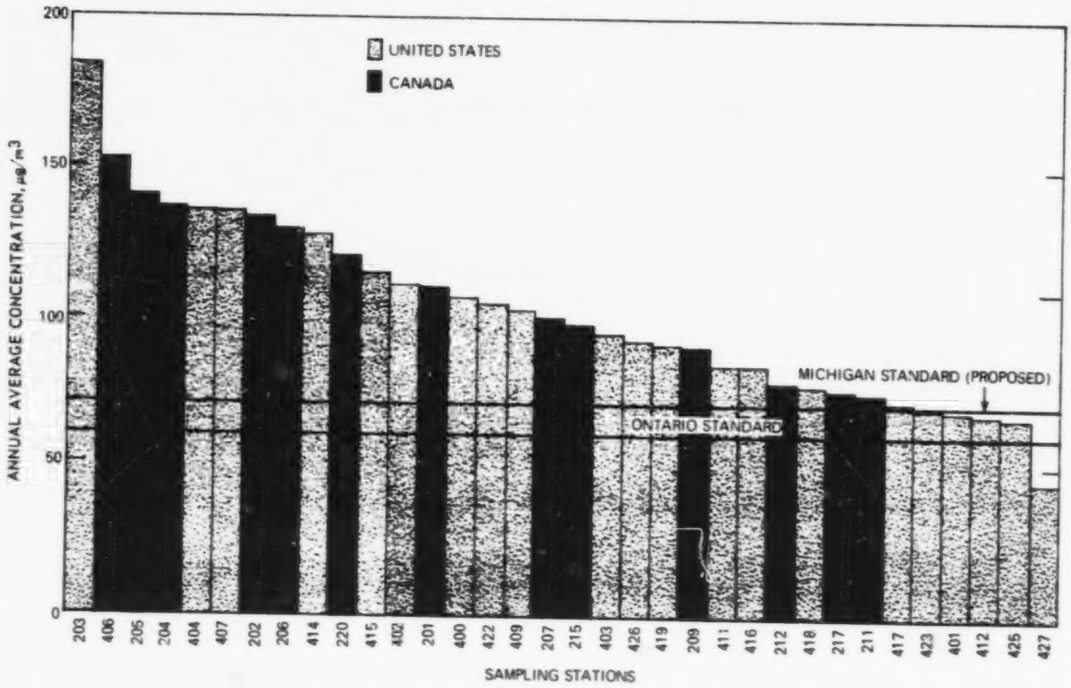

Figure 2-3. Annual average particulate concentrations in Detroit - Windsor area.

and 203 reported annual averages exceeding the Ontario standards. Stations 206, 204, 406, and 203 reported annual averages exceeding the Ontario standards.

2.1.2.3 Suspended Metals - Analyses were made to determine the metallic elements in monthly composite particulate samples collected during April 1968 at 20 stations (17 in the Detroit - Windsor area and 3 in the Port Huron - Sarnia area). The samples were examined quantitatively for 16 metals by emission spectroscopy. In Table 2-11 the measured concentrations for each element are arranged in descending order, and the U. S. National Urban Average values for the metals are indicated. Antimony, bismuth, and cobalt were not detectable in the samples. Four other metals - tin, nickel, vanadium, and titanium - were not found in concentrations higher than the U. S. National Urban Averages. Molybdenum occurred only at the minimum detectable level. Beryllium was above the minimum detectable concentration at one station only. Copper occurred at concentrations above the urban averages at only two stations. Concentrations of the remaining six metals were redetermined by atomic absorption spectroscopy from samples collected in a 10-station network in the Detroit - Windsor area during October 1968. The monthly average concentrations are shown in Table 2-12. This network provided somewhat denser coverage of the River Rouge - Zug Island - Ecorse heavy-industry sections of Detroit than did the network used in April. In spite of this, the U. S. National Urban Average concentrations for cadmium and chromium were exceeded at only one station each, and for zinc at only two stations.

During the October 1968 sampling, manganese exceeded the U. S. National Urban Average at more stations than any other metal. The occurrence of relatively

Table 2-6. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF AVERAGE DAILY SUSPENDED-PARTICULATE CONCENTRATIONS, DETROIT - WINDSOR AREA

Station number	Number of observations	Suspended-particulate concentrations, μg/m^3									
		% of samples ≥ stated value						Maximum observed value	Arithmetic mean	Arithmetic standard deviation	Geometric mean
		90	75	50	25	10	1				
201	114	59	79	107	131	163	272	290	110	41	102
202	116	59	100	130	163	211	299	319	133	54	121
203	99	80	126	167	228	293	390	537	183	87	164
204	84	67	93	124	166	216	326[a]	326	137	50	125
205	93	71	88	122	166	228	471	471	140	71	124
206	67	71	88	117	141	226	400[a]	400	129	65	116
207	109	50	68	90	122	167	265	272	101	44	93
209	102	33	52	78	124	160	279	281	91	53	77
211	88	41	54	75	92	111	154[a]	154	76	27	71
212	95	40	57	70	96	133	202[a]	202	79	35	71
215	65	53	67	93	116	137	213[a]	213	97	37	90
217	87	34	52	73	95	117	217[a]	217	77	34	70
220	86	62	80	112	139	167	575[a]	575	120	68	109
400	72	44	64	97	145	177	280[a]	280	107	55	91
401	110	25	36	59	95	127	218	225	71	47	58
402	100	44	62	96	139	200	410	411	111	65	93
403	199	38	56	89	123	164	180	284	96	51	82
404	103	70	89	121	172	217	295	300	136	61	123
406	197	70	101	138	198	244	370	386	152	70	137
407	92	84	82	117	175	234	284[a]	284	136	68	121
409	176	44	61	89	123	184	357	416	103	64	88
411	108	47	59	78	102	131	177	179	85	33	78
412	214	38	49	63	82	105	179	185	69	30	64
414	203	52	74	110	159	242	369	411	127	71	108
415	108	51	71	94	147	192	368	371	115	66	99
416	117	40	55	78	104	139	255	270	85	41	76
417	104	31	46	66	100	127	204	209	73	38	64
418	110	38	51	71	96	126	218	221	78	37	70
419	91	27	51	82	118	170	328[a]	328	92	57	77
422	110	41	60	92	138	200	317	321	105	60	89
423	92	28	43	60	92	134	239[a]	239	71	40	61
425	110	28	40	58	90	119	234	245	68	39	58
426	86	34	48	78	138	176	293[a]	293	93	55	78
427	82	16	27	42	61	76	129[a]	129	46	24	40

[a] Maximum observed value used when less than 100 observations available.

Table 2-7. PERCENTAGE OF SUSPENDED-PARTICULATE SAMPLES THAT EXCEEDED SPECIFIC CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	% of samples exceeding stated value:						
	65 $\mu g/m^3$	75 $\mu g/m^3$	100 $\mu g/m^3$	125 $\mu g/m^3$	150 $\mu g/m^3$	175 $\mu g/m^3$	200 $\mu g/m^3$
201	86	79	56	31	15	7	4
202	91	87	73	56	40	20	15
203	96	93	84	73	61	45	37
204	93	87	68	48	32	21	13
205	85	77	59	43	30	22	15
206	100	87	59	38	23	15	9
207	78	67	43	25	14	6	5
209	62	54	36	24	15	9	6
211	62	48	19	5	1	0	0
212	63	50	25	12	5	1	1
215	81	71	43	20	6	5	1
217	59	47	22	8	2	2	1
220	88	81	61	37	18	9	1
400	76	68	50	33	21	14	7
401	47	39	22	12	6	6	1
402	73	64	46	32	21	14	10
403	67	58	37	22	13	9	5
404	90	85	70	54	38	26	14
406	100	87	74	61	48	36	26
407	87	81	66	51	36	27	16
409	71	62	42	29	19	11	8
411	71	59	31	13	4	2	0
412	45	32	13	6	2	1	0
414	81	74	56	41	30	22	16
415	78	70	49	33	22	17	10
416	63	52	30	17	9	5	3
417	52	42	23	12	6	2	1
418	57	45	23	12	6	3	2
419	63	55	36	23	15	10	6
422	71	62	44	30	20	11	9
423	47	37	21	12	7	1	1
425	44	35	18	10	6	2	2
426	64	55	37	25	17	9	7
427	19	9	0	0	0	0	0

Table 2-8. PERCENTAGE OF SUSPENDED-PARTICULATE SAMPLES WITHIN SELECTED CONCENTRATION RANGES, DETROIT - WINDSOR AREA

Station number	% of samples within stated ranges:						
	<65 μg/m3	65-75 μg/m3	75-100 μg/m3	100-125 μg/m3	125-150 μg/m3	150-200 μg/m3	>200 μg/m3
201	14	7	23	25	16	11	4
202	9	4	14	17	16	25	15
203	4	3	9	11	12	24	37
204	7	6	19	20	16	19	13
205	15	8	18	16	13	15	15
206	0	13	28	21	15	14	9
207	22	11	24	18	11	3	5
209	38	8	18	12	9	9	6
211	38	14	29	14	4	1	0
212	37	13	25	13	7	4	1
215	19	10	28	23	14	5	1
217	41	12	25	14	6	1	1
220	12	7	20	24	19	17	1
400	24	8	18	17	12	14	7
401	53	8	17	10	6	5	1
402	27	9	18	14	11	11	10
403	33	9	21	15	9	8	5
404	10	5	15	16	16	24	14
406	0	13	13	13	13	22	26
407	13	6	15	15	15	20	16
409	29	9	20	13	10	11	8
411	29	12	28	18	9	4	0
412	55	13	19	7	4	2	0
414	19	7	18	15	11	14	16
415	22	8	21	16	11	12	10
416	37	11	22	13	8	6	3
417	48	10	19	11	6	5	1
418	43	12	22	11	6	4	2
419	37	8	19	13	8	9	6
422	29	9	18	14	10	11	9
423	53	10	16	9	5	5	2
425	56	9	17	8	4	4	2
426	36	9	18	12	8	10	7
427	81	10	9	0	0	0	0

Table 2-9. SEASONAL VARIATIONS IN SUSPENDED-PARTICULATE CONCENTRATIONS, DECEMBER 1967 THROUGH NOVEMBER 1968, DETROIT - WINDSOR AREA

Station number	December - February			March - May		
	Number of observations	Arithmetic mean, μg/m^3	Number of observed values > 200 μg/m^3	Number of observations	Arithmetic mean, μg/m^3	Number of observed values > 200 μg/m^3
201	27	145	3	29	104	0
202	27	176	7	27	104	0
203	22	224	10	26	168	7
204	--	--	--	27	125	2
205	19	161	4	22	135	4
206	23	140	4	27	129	3
207	27	117	3	23	90	0
209	25	120	3	25	92	0
211	--	--	--	29	76	0
212	--	--	--	30	84	0
215	--	--	--	--	--	--
217	--	--	--	21	68	0
220	--	--	--	20	109	0
400	--	--	--	16	110	1
401	20	81	2	29	62	0
402	15	131	2	32	113	5
403	41	90	1	55	78	0
404	21	153	4	29	137	4
406	37	125	2	59	160	17
407	18	94	0	23	178	7
409	25	112	3	55	116	8
411	23	101	0	31	81	0
412	39	64	0	64	74	0
414	41	123	6	63	137	12
415	21	117	2	29	130	4
416	24	80	0	32	86	0
417	18	68	0	31	82	0
418	21	72	0	32	82	0
419	13	67	0	27	114	2
422	19	84	0	32	115	5
423	12	62	0	27	79	0
425	20	56	0	31	69	0
426	--	--	--	26	116	2
427	10	50	0	28	41	0

Table 2-9 (continued). SEASONAL VARIATIONS IN SUSPENDED-PARTICULATE CONCENTRATIONS, DECEMBER 1967 THROUGH NOVEMBER 1968, DETROIT - WINDSOR AREA

Station number	June - August			September - November		
	Number of observations	Arithmetic mean, µg/m3	Number of observed values > 200 µg/m3	Number of observations	Arithmetic mean, µg/m3	Number of observed values > 200 µg/m3
201	31	110	1	29	109	0
202	36	151	7	29	128	4
203	28	186	13	25	184	9
204	31	152	8	26	130	4
205	27	128	2	26	139	4
206	18	116	2	--	--	--
207	32	101	1	28	96	0
209	30	90	0	23	61	0
211	30	78	0	29	74	0
212	37	81	1	28	69	0
215	30	105	1	28	93	0
217	38	83	1	28	75	0
220	38	138	3	28	102	0
400	31	109	2	25	101	1
401	33	79	0	28	62	0
402	28	112	2	25	94	1
403	65	114	6	38	96	0
404	27	141	5	26	114	1
406	59	155	16	42	162	13
407	26	133	5	25	131	3
409	53	101	2	44	85	3
411	32	82	0	22	77	0
412	61	75	0	50	60	0
414	59	140	7	40	109	5
415	29	117	3	29	97	1
416	32	95	1	29	77	0
417	31	78	1	24	60	0
418	33	83	2	24	71	0
419	26	94	1	25	79	0
422	31	106	3	28	106	3
423	31	75	0	22	60	1
425	32	79	1	27	64	0
426	27	96	0	25	68	0
427	19	56	0	25	42	0

Table 2-10. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF 2-HOUR SOILING-INDEX VALUES, PORT HURON - SARNIA AREA

Station number	Number of observations	Coh/1000 lineal ft								
		% of samples ≥ stated value:						Maximum observed value	Geometric mean	Geometric standard deviation
		90	75	50	25	10	1			
151	3,913	0.2	0.3	0.5	0.8	1.3	2.6	6.9	0.5	2.3
152	340	<0.1	0.1	0.2	0.4	0.5	1.0	1.9	0.2	2.2
155	3,469	0.1	0.3	0.4	0.6	0.9	1.8	5.5	0.4	2.0
156	3,518	0.1	0.2	0.2	0.4	0.6	1.0	2.3	0.2	1.9
157	1,053	0.2	0.2	0.3	0.5	0.8	1.6	2.1	0.3	1.9
158	3,973	0.1	0.2	0.4	0.7	1.0	1.9	6.0	0.4	2.3
160	4,229	0.1	0.2	0.4	0.6	0.9	1.8	4.8	0.3	2.1
161	3,726	0.1	0.2	0.3	0.5	0.8	1.5	2.4	0.3	2.2
163	2,354	0.1	0.1	0.2	0.3	0.4	0.8	2.8	0.2	2.1
301	3,704	0.1	0.1	0.3	0.5	0.9	2.1	4.2	0.3	2.5
303	3,539	0.1	0.1	0.3	0.4	0.7	1.4	2.8	0.2	2.2
310	3,467	0.2	0.3	0.7	1.1	1.4	2.3	3.7	0.6	2.4

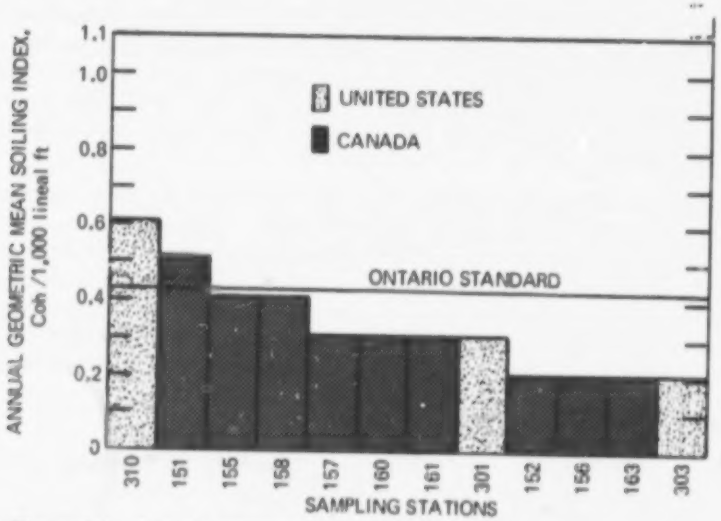

Figure 2-4. Annual geometric mean soiling index in Detroit - Windsor area.

high concentrations of manganese and of iron could be attributed to the steel industry. Lead, which exceeded the U.S. urban average at less than half the sampling stations during this period, is probably introduced into the atmosphere from automobile fuel.

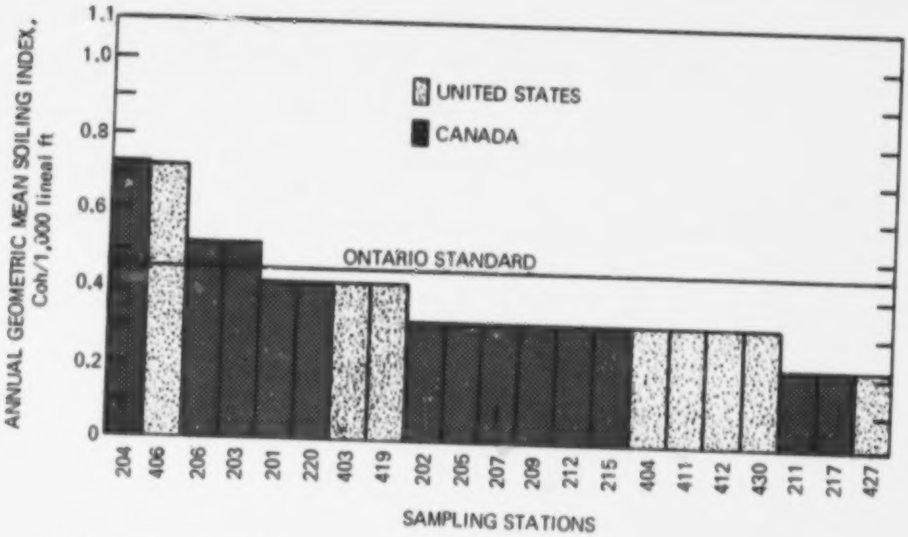

Figure 2-5. Annual geometric mean soiling index in Detroit - Windsor area.

2.1.2.4 Benzo(a)pyrene - Suspended particulate samples were analyzed for benzo(a)pyrene at Stations 202, 303, 401, 406, and 409 for the year. Samples from Stations 201, 203, 205, 206, 207, 209, and 211 were analyzed for December through March. The monthly average values are reported in Table 2-13. Particulate collections from Stations 303, 401, 406, and 409 were each analyzed as composite monthly samples. The 24-hour collections from other stations were analyzed separately and the monthly average concentration computed. Consistently higher values than at other stations were observed at Station 406, the highest occurring in October (16.2 ng/m^3). Higher values also occurred during February at Stations 203, 206, and 209 (9.8, 10.5, and 1.04 ng/m^3, respectively).

2.1.2.5 Fluorides - Fluoride monitoring stations were at two sites in the Port Huron - Sarnia area and three sites in the Detroit - Windsor area. The stations consisted of specially designed sequential samplers using a filter paper impregnated with sodium formate for the chemical sorption of hydrogen fluoride. Sampling was done for six 4-hour periods every third day. The samples were analyzed for fluoride content, both the sorbed hydrogen fluoride and particulate fluorides, by means of a specific ion electrode. The results are reported as 4-hour averages in ppb fluoride at 25° C and 760 mm pressure.

2.1.2.5.1 Port Huron - Sarnia area. Results of sampling in the Port Huron - Sarnia area are shown in Table 2-14. Both sampling stations measured approximately the same fluoride concentrations. The maximum concentrations experienced, 2.2 ppb at Station 305 and 1.3 at Station 307, were above the limit of 1.0 ppb specified by Ontario. The arithmetic mean, however, was 0.3 ppb at Station 305 and 0.2 ppb at Station 307.

Seasonal variations in fluoride concentrations are given in Table 2-15. Slightly higher fluoride concentrations were detected during summer at both stations than during spring and fall. Winter values are not available.

Table 2-11. METAL CONCENTRATIONS[a] AT SELECTED STATIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS, APRIL 1968

Metal	Minimum detectable level, µg/m³	Concentration, µg/m³									
Antimony	0.04	ND[b]	ND	ND	ND	ND	ND	ND	ND	ND	ND
Beryllium	0.0002	(414)[d] 0.0004	(406) 0.0002	(202) 0.0002	(211) 0.0002[c]	ND	ND	ND	ND	ND	ND
Bismuth	0.001	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	0.011	(414) 0.021	(201) 0.018	(406) 0.017	(202) 0.011[c]	ND	ND	ND	ND	ND	ND
Chromium	0.006	(422) 0.035	(415) 0.027	(414) 0.025	(202) 0.023	(201) 0.019	(406) 0.019	(303) 0.016	(417) 0.016	(205) 0.014[c]	(211) 0.013
Cobalt	0.006	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	0.01	(303) 0.13	(427) 0.11	(414) 0.09[c]	(422) 0.08	(417) 0.08	(415) 0.07	(310) 0.07	(209) 0.06	(406) 0.06	(212) 0.05
Iron	0.16	(202) 5.3	(406) 4.7	(415) 4.6	(414) 4.4	(422) 4.4	(201) 3.4	(211) 2.7	(417) 2.7	(411) 2.7	(419) 2.3
Lead	0.04	(414) 1.2	(401) 1.1	(422) 1.1	(419) 0.92	(417) 0.78[c]	(415) 0.76	(205) 0.64	(310) 0.63	(202) 0.56	(201) 0.55
Manganese	0.01	(422) 0.17	(202) 0.17	(406) 0.16	(201) 0.15	(414) 0.15	(415) 0.15	(419) 0.12	(411) 0.11	(205) 0.10[c]	(211) 0.10
Molybdenum	0.003	(406) 0.003	(202) 0.003	(211) 0.003[c]	ND	ND	ND	ND	ND	ND	ND
Nickel	0.006	(202) 0.025[c]	(201) 0.023	(422) 0.023	(303) 0.023	(414) 0.021	(406) 0.020	(415) 0.020	(205) 0.020	(204) 0.016	(211) 0.015
Tin	0.001	(414) 0.015[c]	(422) 0.009	(419) 0.008	(406) 0.004	(202) 0.004	(211) 0.002	(205) 0.002	(201) 0.002	(209) 0.002	(212) 0.002
Titanium	0.01	(414) 0.04[c]	(406) 0.04	(415) 0.03	(202) 0.02	(211) 0.02	(204) 0.02	(201) 0.02	(422) 0.02	(212) 0.01	ND
Vanadium	0.003	(303) 0.022[c]	(310) 0.007	(414) 0.007	(204) 0.007	(161) 0.006	(205) 0.006	(406) 0.006	(422) 0.005	(202) 0.005	(211) 0.004
Zinc	0.12	(414) 2.5	(406) 1.7	(303) 1.5	(310) 1.3	(415) 0.91	(411) 0.90	(202) 0.89	(422) 0.75	(419) 0.59[c]	(417) 0.35

Table 2-11 (continued). METAL CONCENTRATIONS[a] AT SELECTED STATIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS, APRIL 1968.

Metal	Minimum detectable level, µg/m^3	Concentration, µg/m^3									
Antimony	0.04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Beryllium	0.0002	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bismuth	0.001	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	0.011	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	0.006	(310) 0.013	(419) 0.009	(209) 0.009	ND	ND	ND	ND	ND	ND	ND
Cobalt	0.006	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	0.01	(202) 0.04	(211) 0.04	(205) 0.04	(201) 0.03	(204) 0.03	(217) 0.03	(207) 0.03	(161) 0.03	(419) 0.03	(411) 0.02
Iron	0.16	(205) 2.2	(204) 2.0	(209) 1.9	(212) 1.8	(310) 1.4[c]	(303) 1.4	(217) 1.1	(161) 0.95	(207) 0.92	(427) 0.83
Lead	0.04	(303) 0.51	(204) 0.47	(209) 0.41	(211) 0.35	(207) 0.35	(212) 0.30	(161) 0.28	(217) 0.26	(411) 0.24	(427) 0.17
Manganese	0.01	(417) 0.11	(209) 0.09	(212) 0.09	(204) 0.08	(303) 0.08	(207) 0.06	(217) 0.06	(310) 0.05	(427) 0.05	(161) 0.04
Molybdenum	0.003	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	0.006	(209) 0.015	(161) 0.015	(310) 0.015	(417) 0.014	(411) 0.012	(212) 0.012	(419) 0.010	(207) 0.009	(217) 0.009	ND
Tin	0.001	(204) 0.002	(303) 0.002	(161) 0.001	ND	ND	ND	ND	ND	ND	ND
Titanium	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium	0.003	(209) 0.004	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	0.12	(211) 0.26	(204) 0.19	(201) 0.14	ND	ND	ND	ND	ND	ND	ND

[a] Data for each metal are presented in order of decreasing concentrations.
[b] ND = not detectable.
[c] National urban average.
[d] Station numbers are given in parentheses.

Table 2-12. METAL CONCENTRATIONS AT SELECTED STATIONS DETROIT - WINDSOR AREA, OCTOBER 1968[a]

Metal	Concentration, µg/m^3									
Cadmium	(203)[b] 0.013	(414) 0.009	(406) 0.007	(202) 0.006	(212) 0.004	(217) 0.004	(403) 0.004	(409) 0.004	(220) 0.003	(425) 0.002
Chromium	(212) 0.021	(220) 0.011	(406) 0.008	(414) 0.008	(202) 0.006	(403) 0.006	(409) 0.003	(217) 0.002	(425) 0.002	(203) 0.000
Iron	(406) 8.6	(414) 4.2	(203) 3.5	(403) 2.9	(220) 2.8	(202) 2.5	(212) 1.6	(217) 1.6	(425) 1.6	(409) 1.4
Lead	(414) 2.55	(406) 1.25	(403) 0.98	(203) 0.97	(202) 0.79	(212) 0.66	(425) 0.64	(409) 0.59	(220) 0.58	(217) 0.54
Manganese	(406) 0.28	(203) 0.21	(220) 0.20	(414) 0.16	(202) 0.15	(403) 0.14	(212) 0.12	(217) 0.10	(409) 0.08	(425) 0.06
Zinc	(414) 1.02	(406) 0.80	(203) 0.63	(403) 0.55	(202) 0.34	(220) 0.34	(409) 0.24	(217) 0.23	(212) 0.22	(425) 0.16

[a] Values were determined by atomic absorption analysis and are presented in the order of decreasing concentrations.

[b] Station numbers in parentheses.

2.1.2.5.2 Detroit - Windsor area. Fluoride data for the Detroit - Windsor area are summarized in Table 2-14. Maximum values at the three stations were above the 1.0 ppb level. The concentrations at Stations 202 and 420 were about the same, but those at 411 were considerably lower. The maximum concentration was 2.9 ppb at Station 202; the same station exceeded 2.7 ppb for 1 percent of the observations.

Seasonal variations (Table 2-16) indicate that higher fluoride concentrations existed during summer than during fall or spring at Station 202. Data for winter were not available.

2.2 DUSTFALL

Particulates which settle from the atmosphere and are measured in dustfall gauges are coarse in size, mainly 20 microns and above. Although dustfall amounts often vary in accord with concentrations of other contaminants which may be responsible for health effects, settleable coarse particles are not considered to be of concern from the health aspect. The chief problem from dustfall is property damage. Buildings, motor vehicles, furnishings, etc., are adversely affected by dust deposition, so that cleaning costs are increased. Frequently, the particles contain adsorbed acidic materials or other corrosive substances and may be particularly damaging.

2.2.1 Air Quality Criteria

Quantitative relationships between the amount of dustfall and the severity of property damage or inconvenience to the community have not been established. The

Table 2-13. AVERAGE CONCENTRATIONS OF BENZO(A)PYRENE, PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS, DECEMBER 1967 THROUGH NOVEMBER 1968
($\mu g/m^3$)

Date	Station number											
	201	202	203[a]	205	206	207	209	211	303[b]	401[a]	406[a]	409[a]
Dec	--	2.1	3.8	4.1	1.3	1.2	1.7	--	1.1	--	5.9	2.1
Jan	2.3	2.9	4.9	3.9	1.0	0.8	1.9	--	1.4	2.1	6.1	1.5
Feb	1.6	1.6	9.8	4.3	10.5	8.6	10.4	--	1.1	1.7	3.4	1.4
Mar	1.3	1.1	3.6	1.8	0.6	--	0.9	0.4	1.3	1.3	14.9	1.7
Apr		1.4							1.0	7.2	6.1	0.8
May		0.4							1.0	1.0	3.4	0.9
Jun		2.4							0.9	0.9	4.3	1.0
Jul		0.7							1.0	1.0	2.0	1.0
Aug		1.0							0.6	0.7	2.8	0.7
Sep		5.9							0.6	0.8	12.0	0.7
Oct		1.4							0.8	1.1	16.2	0.6
Nov		4.6							0.6	1.1	6.7	1.0

[a] Individual particle collections were pooled and analyzed as a monthly composite sample. At all other stations, individual particle collections were analyzed and the values averaged.

[b] This station is in the Port Huron - Sarnia Area. All other stations are in the Detroit - Windsor Area.

Table 2-14. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF AVERAGE FLUORIDE CONCENTRATIONS, 4-HOUR SAMPLES

Station number	Sampling period	Number of samples	Concentration, ppb						Maximum value	Arithmetic mean	Arithmetic standard deviation
			% of observation $\geqq$ stated value:								
			90	75	50	25	10	1			
Port Huron - Sarnia Area											
305	4/68-10/68	231	0.1	0.2	0.2	0.3	0.4	0.9	2.2	0.3	0.2
307	4/68-10/68	244	0.1	0.1	0.2	0.3	0.4	0.9	1.3	0.2	0.2
Detroit - Windsor Area											
202	4/68-10/68	201	0.1	0.2	0.4	0.7	0.9	2.7	2.9	0.5	0.4
411	5/68-9/68	87	0.1	0.1	0.2	0.2	0.3	---	0.8	0.2	0.1
420	6/68-10/68	200	0.1	0.2	0.3	0.4	0.9	1.5	2.0	0.4	0.3

Table 2-15. SEASONAL VARIATIONS IN FLUORIDE CONCENTRATIONS, 4-HOUR SAMPLES, IN PORT HURON - SARNIA AREA, 1968

Sampling period	Station number	Number of samples	Arithmetic mean, ppb	Geometric mean, ppb	Concentrations exceeded by 1 % of samples, ppb	Concentrations exceeded by 10 % of samples, ppb
Mar-May	305	27	0.2	0.2	0.8	0.5
	307	41	0.2	0.1	0.9	0.3
June-Aug	305	132	0.3	0.3	1.4	0.5
	307	133	0.3	0.2	1.0	0.4
Sept-Nov	305	72	0.2	0.2	0.8	0.4
	307	72	0.2	0.2	0.5	0.3

Table 2-16. SEASONAL VARIATIONS IN FLUORIDE CONCENTRATIONS, 4-HOUR SAMPLES, IN DETROIT - WINDSOR AREA, 1968

Sampling period	Station number	Number of samples	Arithmetic mean, ppb	Geometric mean, ppb	Concentrations exceeded by 1% of samples, ppb	Concentrations exceeded by 10% of samples, ppb
Mar-May	202	58	0.4	0.3	0.9	0.8
	411	6	0.2	0.2	0.3	0.3
	420	--	---	---	---	---
June-Aug	202	59	0.8	0.6	2.9	1.2
	411	48	0.2	0.2	0.8	0.3
	420	135	0.4	0.3	1.5	0.9
Sept-Nov	202	84	0.4	0.4	2.6	0.7
	411	33	0.2	0.2	0.5	0.3
	420	65	0.4	0.3	1.6	0.8

Ontario Air Quality Standards, however, do include a standard for dustfall, previously presented in the introduction to this section.

2.2.2 Measured Dustfall

Dustfall samples were collected over monthly periods using a plastic container with a 7.5-inch opening. Weights of both the soluble and insoluble portions of each sample were obtained. The data, expressed as tons of dustfall per square mile per month (tons/mi^2-month), represent the sum of the weights of soluble and insoluble solids.

2.2.2.1 Port Huron - Sarnia Area - Dustfall samples were collected at 29 locations in the Port Huron - Sarnia area. The statistical summary given in Table 2-17 shows the number of samples with dustfall in certain ranges. Of the 269 samples, only nine yielded dustfall values equal to or greater than 40 tons/mi^2-month. The

Table 2-17. OCCURRENCE OF MONTHLY DUSTFALL WITHIN SELECTED RANGES IN PORT HURON - SARNIA AREA
(Stations with six or more observations)

Station number	Number of observations	Dustfall, tons/mi^2-mo			
		10	10-24	25-39	40
151	7	-	3	2	2
153	8	2	6	-	-
154	8	-	2	5	1
155	8	-	5	2	1
156	9	1	7	1	-
158	9	-	7	2	-
159	9	-	6	2	1
160	9	-	5	4	-
161	9	1	6	2	-
162	9	-	6	2	1
163	9	-	7	2	-
164	9	1	7	1	-
165	8	2	5	1	-
166	9	-	8	1	-
303	12	-	10	2	-
307	12	4	8	-	-
308	9	-	2	6	1
310	12	-	4	7	1
311	12	4	6	2	-
312	11	-	7	3	1
313	12	4	6	2	-
314	11	7	4	-	-
315	12	8	4	-	-
316	11	8	3	-	-
317	11	-	9	2	-
318	12	8	4	-	-
319	12	7	5	-	-

eight stations that reported the nine observations of dustfall equal to or exceeding 40 tons/mi^2-month each had mean dustfall values of 25 tons/mi^2-month or greater, nearly twice the Ontario annual standard.

The areal distribution of dustfall is shown in Figure 2-6. The locations of the eight stations with measured dustfall exceeding 40 tons/mi^2-month are indicated by "Δ's".

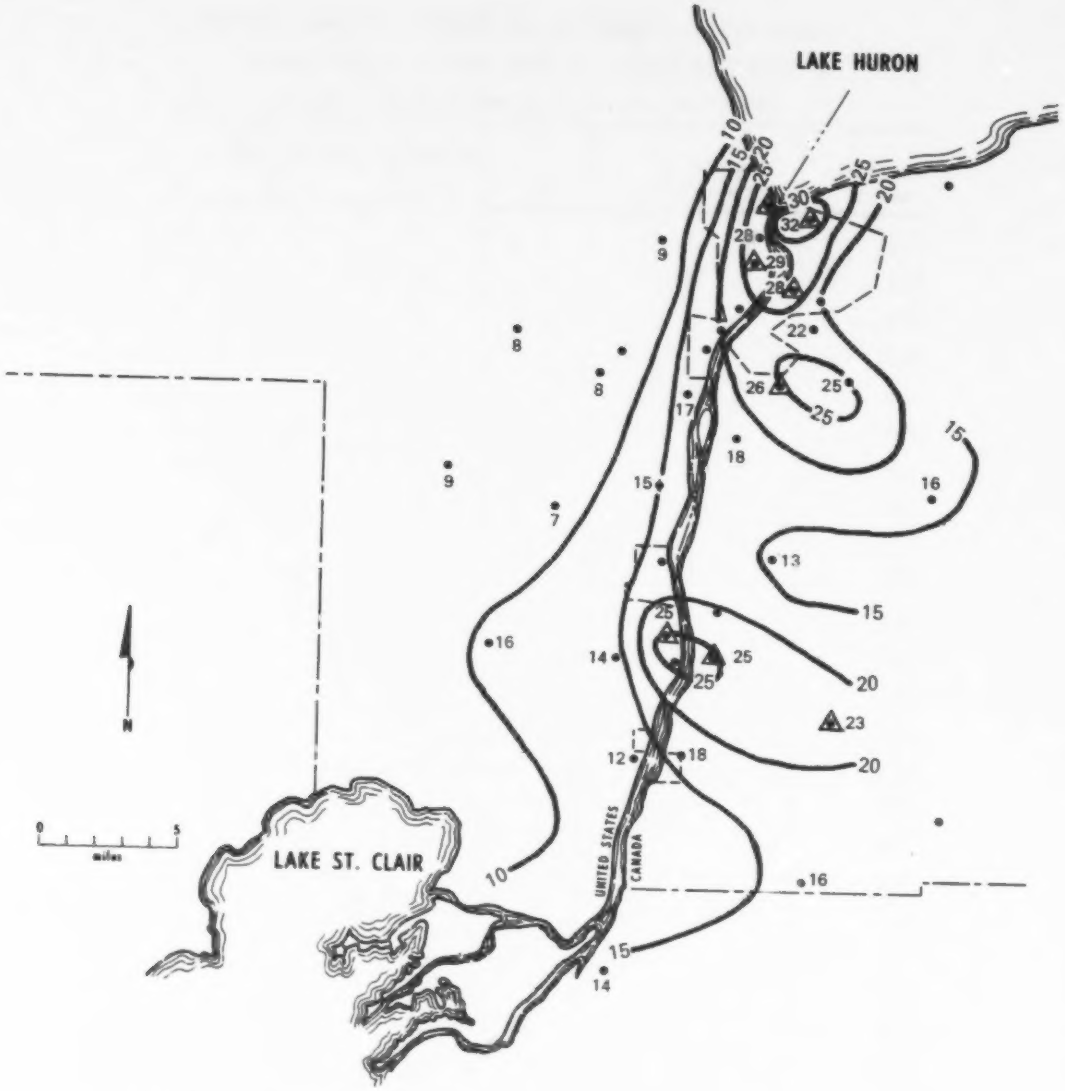
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Figure 2-6. Dustfall (tons/mi^2-mo) for December 1967 through November 1968 (stations taking samples for 6 or more months).

2.2.2.2 Detroit - Windsor Area - There were 38 dustfall sampling stations in the Detroit - Windsor area. Maximum, minimum, and average values are given in Table 2-18. Forty-five of the 397 samples had dustfall exceeding 40 tons/mi^2-month, and all 45 occurred at 10 locations. The value of 40 tons/mi^2-month was exceeded in all 12 of the samples at Station 406, in 10 of the 11 samples at Station 404, and in 8 of 11 samples at Station 203. The number of occurrences of dustfall amounts in various ranges is given in Table 2-19.

The geographic distribution of average dustfall is shown in Figure 2-7. The central commercial-industrial areas of Windsor and Detroit show heavy dustfall,

Table 2-18. DUSTFALL IN DETROIT - WINDSOR AREA

Station number	Number of samples	Dustfall, tons/mi^2-mo Maximum value	Arithmetic mean	Arithmetic standard deviation
201	12	42	23	8
202	12	41	19	8
203	11	68	42	11
205	12	107	34	25
206	8	28	19	6
207	12	28	14	6
209	12	18	12	3
210	11	54	30	12
211	7	15	10	2
212	9	21	16	4
213	11	20	10	4
214	9	28	17	8
215	12	28	12	6
216	12	24	12	6
217	6	18	10	4
218	12	32	16	7
219	12	17	11	4
220	7	39	23	10
400	3	22	17	5
401	9	26	15	6
402	11	47	31	10
403	12	24	13	6
404	11	123	62	39
406	12	82	62	12
407	11	61	41	12
409	11	38	24	9
411	12	24	14	5
412	12	38	13	9
413	10	37	22	7
414	12	44	28	8
415	11	38	19	10
416	12	39	20	9
417	12	29	14	7
418	11	25	14	6
419	9	21	14	5
422	11	36	20	7
423	10	29	14	7
425	12	35	17	9

with the heaviest dustfall occurring in Detroit, south of the city's center.

2.3 SULFUR DIOXIDE

Sulfur dioxide is one of the most abundant pollutants in urban atmospheres because of its widespread production through fuel burning. All fossil fuels except refined natural gas contain sulfur, which is converted predominantly to sulfur dioxide in combustion.

2.3.1 Air Quality Criteria

Information available throughout the world on the effects of sulfur dioxide has been exhaustively examined and documented by the U. S. National Air Pollution

Table 2-19. OCCURRENCE OF MONTHLY DUSTFALL WITHIN SELECTED RANGES IN DETROIT - WINDSOR AREA

Station number	Number of samples	Dustfall, tons/mi^2-mo			
		<10	10-24	25-39	$\geq$40
201	12	-	8	3	1
202	12	1	10	-	1
203	11	-	-	3	8
205	12	1	2	7	2
206	8	-	6	2	-
207	12	2	9	1	-
209	12	2	10	-	-
210	11	-	4	5	2
211	7	3	4	-	-
212	9	1	8	-	-
213	11	6	5	-	-
214	9	2	6	1	-
215	12	5	6	1	-
216	11	5	6	-	-
217	6	3	3	-	-
218	12	1	9	2	-
219	12	6	6	-	-
220	7	-	5	2	-
401	9	1	6	2	-
402	11	-	4	4	3
403	12	4	8	-	-
404	11	-	-	1	10
406	12	-	-	-	12
407	11	-	-	6	5
409	11	-	5	6	-
411	12	2	10	-	-
412	12	6	4	2	-
413	10	-	6	4	-
414	12	-	5	6	1
415	11	-	9	2	-
416	12	1	8	3	-
417	12	2	8	2	-
418	11	3	7	1	-
419	9	2	7	-	-
422	11	-	9	2	-
423	10	2	7	1	-
425	12	1	8	3	-

Control Administration.[3] The publication defines air quality criteria for sulfur oxides and has been used for the assessment of the significance of sulfur dioxide concentrations occurring in the study areas covered by this report.

Air quality standards for sulfur dioxide have been established by several states in the U. S. Others are now considering standards following the publication of the U. S. Air Quality Criteria, and some of those already using standards may modify them. The Ontario standards and proposed Michigan standards for sulfur dioxide were given in the introduction to this section.

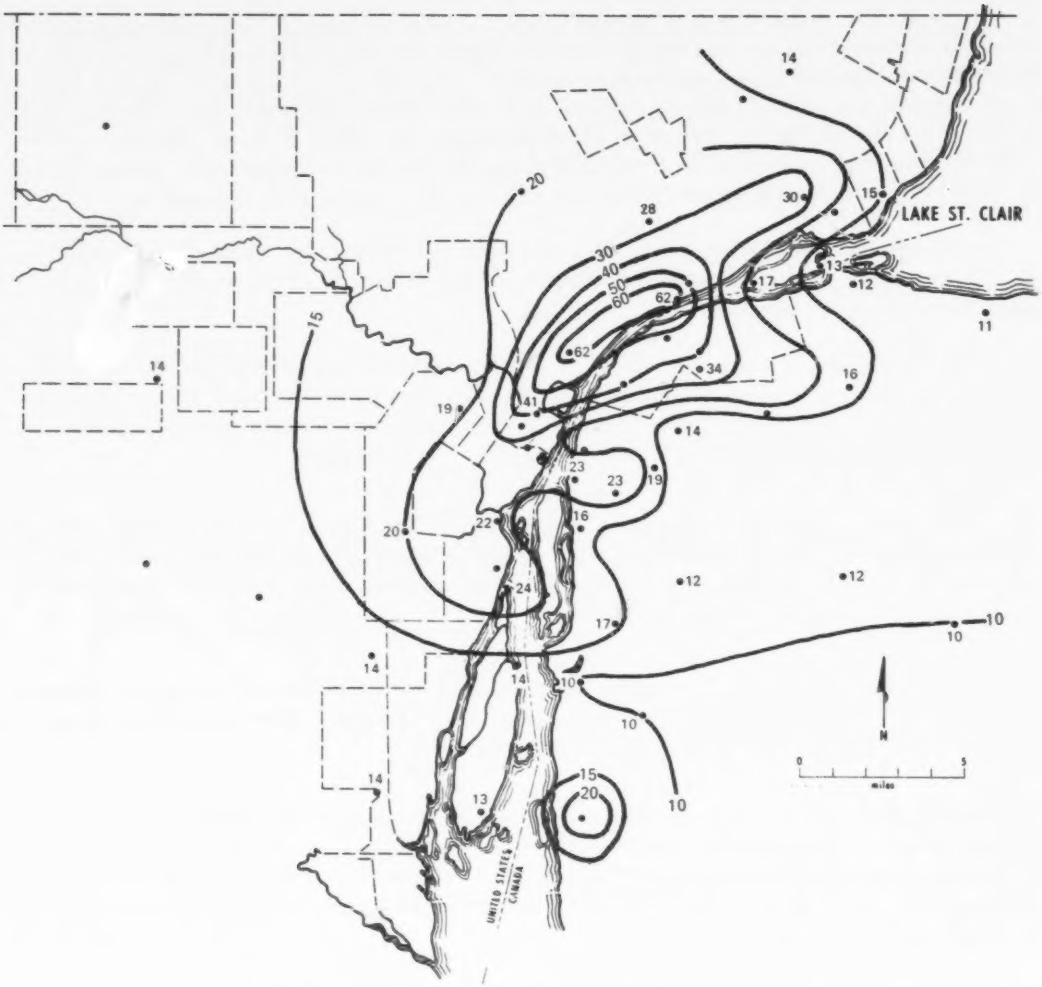
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Figure 2-7. Geographic distribution of average dustfall, tons/mi^2-mo.

2.3.2 Measured Air Quality

2.3.2.1 Sulfur Dioxide Measurements - Atmospheric sulfur dioxide concentrations were measured at 26 locations in the Port Huron - Sarnia and Detroit - Windsor areas. At the Canadian stations, sulfur dioxide was measured by continuous-recording electroconductivity analyzers, except at Station 202 where a continuous coulometric analyzer was used from August through November 1968. The data reported are average values for 1-hour periods.

At U. S. stations, 2-hour average concentrations were measured at Station 303 from March through November 1968, Station 310 from January through April 1968, and Station 408 from February through May 1968, using sequential samplers and spectrophotometric techniques. At all other U. S. stations, continuous coulometric analyzers were used and average values for 1-hour periods were reported.

2.3.2.1.1 Port Huron - Sarnia area. The precentage frequency of occurrence of hourly average and daily average sulfur dioxide concentrations for the Port Huron - Sarnia area is given in Tables 2-20 and 2-21, together with maximum and average values for the entire period of observation at each station. All stations measured hourly average concentrations of sulfur dioxide equal to or greater than the 0.25 ppm limit specified by the Ontario regulations. Seven of the 11 locations had hourly average concentrations in excess of 0.40 ppm.

All but three stations (157, 163, and 305) exceeded the Ontario standard of 0.10 ppm sulfur dioxide concentration, and four of the 11 equaled or exceeded 0.20 ppm for a 24-hour period.

From the mean values of hourly concentrations, only two stations, 152 and 310, indicate annual average sulfur dioxide concentrations as high as the Ontario standard. Two stations reported annual average sulfur dioxide concentrations greater than the proposed Michigan standard of 0.035 ppm.

2.3.2.1.2 Detroit - Windsor area. Table 2-22 gives the percentage frequency of occurrence of hourly and 24-hourly values of atmospheric sulfur dioxide concentrations for 15 locations in the Detroit - Windsor area. Average and maximum values of concentration are also given.

All stations, except 411, showed average concentrations equal to or greater than the 0.02 ppm limit of the Ontario standard. Station 411 reached this limit for hourly averages, but not for daily averages.

Only one station, 208, measured an annual average concentration of 0.05 ppm. Ten stations exceeded the 1-hour limit set by the Ontario standards. Eight locations exceeded the Ontario limit for 24-hour average concentrations. Only Stations 208 and 408 exceeded the Michigan standard of 0.035 ppm for an annual average sulfur dioxide concentration.

2.3.2.2 Sulfation Rate Measurements - The conversion of exposed lead peroxide to lead sulfate by atmospheric sulfur dioxide provides a static method of obtaining an index of the presence of sulfur dioxide in the atmosphere. This index is used as a measure of the effects of sulfur dioxide on materials, such as fabrics, metals, paints, masonry, etc.

2.3.2.2.1 Port Huron - Sarnia area. Thirty-two locations in the Port Huron - Sarnia area were used to study sulfation rate. Table 2-22 summarizes the data. At all stations, the mean value over the period of observation equaled or exceeded the 0.4 mg SO_3/100 cm^2-day limit set by the Ontario air quality standard. Sixteen of the stations had average values equaling or exceeding 1.0 mg SO_3/100 cm^2-day. It should be noted that those stations reporting mean values of 0.5 mg SO_3/100 cm^2-day or less did not collect samples during December, January, and February.

During February 1969 an intensive survey was made of sulfation rates in the Port Huron - Sarnia area. Sulfation sensors were installed at 121 locations along lines parallel to the St. Clair River, with scattered additional sensors located in Sarnia as well as up to 10 miles from the river.

Table 2-20. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY SULFUR DIOXIDE CONCENTRATIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≥ stated value:								
		90	75	50	25	10	1			
Port Huron - Sarnia area										
151	7,765	<0.01	<0.01	<0.01	0.02	0.09	0.24	0.53	0.02	0.05
152	1,438	<0.01	<0.01	0.01	0.03	0.07	0.24	0.34	0.03	0.04
155	5,959	<0.01	<0.01	<0.01	0.03	0.07	0.23	0.71	0.02	0.05
156	7,774	<0.01	<0.01	0.01	0.02	0.04	0.12	0.52	0.02	0.03
157	3,922	<0.01	0.01	0.02	0.03	0.05	0.12	0.28	0.02	0.02
158	8,540	<0.01	<0.01	<0.01	0.02	0.05	0.20	0.71	0.02	0.04
161	7,662	<0.01	<0.01	<0.01	0.02	0.07	0.24	0.48	0.02	0.05
163	2,789	<0.01	0.01	0.02	0.02	0.04	0.08	0.26	0.02	0.02
303[a]	1,349	<0.01	<0.01	0.01	0.02	0.05	0.21	0.57	0.02	0.04
305	1,579	<0.01	0.01	0.01	0.02	0.03	0.10	0.25	0.02	0.02
310[a]	547	<0.01	0.01	0.01	0.02	0.07	0.17	0.40	0.03	0.04
310	2,656	<0.01	0.01	0.01	0.02	0.04	0.14	0.32	0.02	0.03
Detroit - Windsor area										
202	855	<0.01	<0.01	0.02	0.03	0.05	0.19	0.84	0.02	0.05
202	1,919	<0.01	<0.01	0.02	0.04	0.06	0.13	0.31	0.03	0.03
208	2,047	0.01	0.02	0.04	0.05	0.11	0.22	0.35	0.05	0.05
211	310	<0.01	<0.01	0.01	0.02	0.03	0.05	0.15	0.02	0.02
212	688	0.01	0.01	0.02	0.02	0.03	0.07	0.11	0.02	0.01
220	1,280	<0.01	0.01	0.02	0.03	0.05	0.15	0.20	0.02	0.02
403	4,982	0.01	0.01	0.02	0.03	0.05	0.14	0.30	0.02	0.03
404	5,739	0.01	0.01	0.02	0.04	0.07	0.20	0.49	0.03	0.04
408[a]	487	<0.01	<0.01	0.02	0.05	0.08	0.20	0.33	0.04	0.04
408	2,747	<0.01	<0.01	0.01	0.02	0.04	0.14	0.27	0.02	0.03
411	687	<0.01	<0.01	0.01	0.02	0.04	0.09	0.13	0.02	0.02
412	556	0.01	0.01	0.01	0.03	0.06	0.22	0.33	0.03	0.04
415	2,735	<0.01	0.01	0.01	0.02	0.05	0.23	0.37	0.02	0.04
416	2,686	<0.01	0.01	0.01	0.01	0.03	0.14	0.25	0.02	0.02
419	2,165	0.01	0.01	0.01	0.02	0.03	0.09	0.29	0.02	0.02
423	1,470	<0.01	0.01	0.01	0.02	0.03	0.08	0.20	0.02	0.02
430	2,828	<0.01	0.01	0.02	0.03	0.06	0.15	0.25	0.02	0.03

[a] Two-hour samples.

Table 2-21. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY SULFUR DIOXIDE CONCENTRATIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS

Station number	Number of samples	Concentration, ppm % of samples ≥ stated value: 90	75	50	25	10	1	Maximum value	Arithmetic mean
Port Huron - Sarnia area									
151	343	<0.01	<0.01	<0.01	0.03	0.07	0.19	0.29	0.03
152	61	<0.01	0.01	0.02	0.03	0.06	-	0.20	0.03
155	263	<0.01	<0.01	0.01	0.03	0.05	0.11	0.14	0.02
156	339	<0.01	<0.01	<0.01	0.02	0.03	0.09	0.16	0.02
157	170	<0.01	0.01	0.02	0.02	0.04	0.07	0.08	0.02
158	362	<0.01	<0.01	<0.01	0.02	0.04	0.08	0.13	0.02
161	329	<0.01	<0.01	0.01	0.02	0.05	0.17	0.26	0.02
163	121	<0.01	<0.01	0.01	0.02	0.03	0.05	0.06	0.02
303[a]	118	<0.01	<0.01	0.01	0.02	0.04	0.17	0.24	0.02
305	91	<0.01	<0.01	0.01	0.02	0.02	--	0.06	0.02
310	201	<0.01	<0.01	0.01	0.02	0.05	0.11	0.11	0.02
Detroit - Windsor area									
202	144	<0.01	<0.01	0.02	0.03	0.06	0.16	0.17	0.03
208	98	0.02	0.03	0.04	0.06	0.09	--	0.13	0.05
211	18	<0.01	<0.01	0.01	0.02	0.02	--	0.03	0.02
212	36	<0.01	<0.01	0.01	0.02	0.02	--	0.04	0.02
220	81	<0.01	0.01	0.02	0.02	0.04	--	0.07	0.02
403	280	0.01	0.01	0.02	0.03	0.04	0.08	0.08	0.02
404	275	<0.01	0.01	0.02	0.04	0.06	0.11	0.14	0.03
408	173	0.01	0.01	0.02	0.03	0.05	0.11	0.12	0.02
411	51	<0.01	<0.01	0.01	0.22	0.03	--	0.06	0.01
412	73	<0.01	0.01	0.02	0.02	0.04	--	0.15	0.02
415	143	<0.01	<0.01	0.01	0.02	0.06	0.15	0.18	0.02
416	135	<0.01	<0.01	0.01	0.02	0.03	0.13	0.14	0.02
419	107	<0.01	<0.01	0.01	0.02	0.02	0.05	0.06	0.02
423	73	<0.01	<0.01	0.01	0.02	0.03	--	0.06	0.02
430	140	<0.01	0.01	0.02	0.03	0.04	0.12	0.13	0.02

[a] Two-hour samples.

Table 2-22. SULFATION[a] IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, mg SO_3/100 cm^2-day		
		Maximum value	Arithmetic mean	Arithmetic standard deviation
151	11	2.8	1.6	0.6
152	5	2.6	1.4	0.7
153	11	2.0	0.6	0.5
154	11	2.2	1.0	0.5
155	11	1.8	1.3	0.3
156	11	1.9	1.1	0.4
157	11	1.6	1.0	0.3
158	11	1.7	1.0	0.4
159	11	3.1	1.9	0.6
160	11	2.2	1.2	0.4
161	11	2.0	1.1	0.4
162	11	2.1	0.8	0.8
163	8	0.7	0.4	0.3
164	8	0.7	0.4	0.2
165	8	0.9	0.5	0.3
166	8	0.8	0.6	0.1
167	8	0.8	0.6	0.1
170	3	1.2	0.9	0.3
301	11	2.2	1.2	0.4
303	11	2.3	1.2	0.5
305	10	1.7	1.0	0.5
307	11	1.4	0.7	0.3
308	11	2.1	1.0	0.4
310	11	3.1	1.4	0.7
311	11	1.6	0.9	0.4
312	11	2.0	1.1	0.4
313	11	2.1	0.8	0.5
314	11	1.8	0.9	0.4
315	11	1.7	0.7	0.4
316	11	1.5	0.8	0.3
317	11	1.7	0.6	0.5
318	10	1.5	0.6	0.4
319	10	1.3	0.6	0.3

[a] Determined by the lead-peroxide candle method.

The pattern of sulfation rates measured during this survey is given in Figure 2-8. Centers of high sulfation rates appear in the southern portion of Sarnia and in the area east of Marine City, Michigan, and Bickford and Sombra, Ontario.

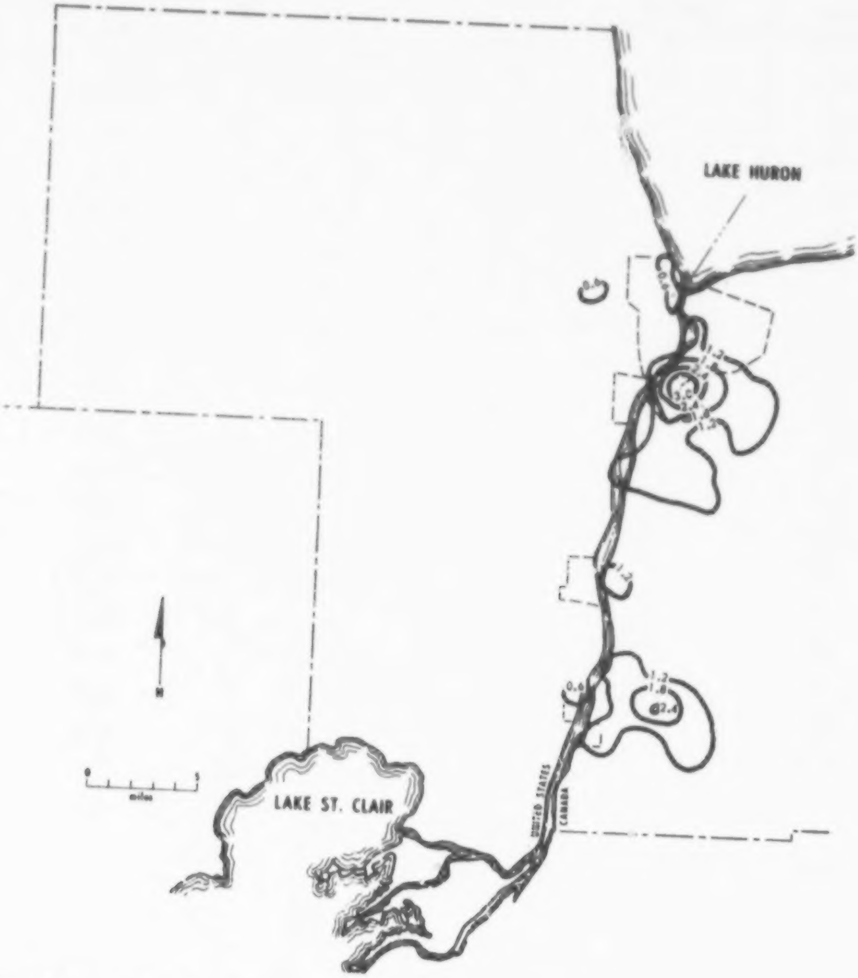

Figure 2-8. Pattern of sulfation rates during February 1969 in Port Huron - Sarnia area.

2.3.2.2.2 Detroit - Windsor area. The sulfation rate data collected at the 41 stations in the Detroit - Windsor area are summarized in Table 2-23. Only 17 stations had average rates less than 1.0 mg $SO_3/100\ cm^2$-day. Only one station had a rate as low as 0.4, the Ontario standard.

Only one station had a rate as low as 0.04, the Ontario standard. The pattern of annual average sulfation rates shown by Figure 2-9 clearly indicates the effects of industrial activity along the Detroit River.

Table 2-23. SULFATION IN DETROIT - WINDSOR AREA[a]

Station number	Number of samples	Concentration, mg SO_3/100 cm^2-day Maximum value	Arithmetic mean	Arithmetic standard deviation
201	11	2.0	1.1	0.4
202	11	2.6	1.7	0.6
203	11	3.4	2.4	0.6
205	11	2.7	1.2	0.6
206	7	1.6	1.0	0.4
207	11	2.6	1.1	0.6
209	11	2.1	1.1	0.4
210	9	2.8	1.2	0.9
211	8	1.0	0.8	0.2
212	8	0.8	0.7	0.1
213	11	1.3	0.7	0.3
214	7	1.7	1.1	0.4
215	11	1.2	0.8	0.3
216	10	1.3	0.8	0.3
217	8	0.8	0.6	0.2
218	10	1.9	0.9	0.5
219	10	1.3	0.7	0.4
220	4	1.5	1.1	0.4
400	11	2.9	1.5	0.6
401	11	2.0	1.0	0.4
402	11	2.6	1.2	0.6
403	10	2.8	1.4	0.6
404	11	3.4	1.7	0.7
406	11	3.3	2.1	0.6
407	11	3.6	1.9	0.7
409	11	1.6	1.1	0.3
411	11	1.9	1.2	0.4
412	10	1.7	1.0	0.3
413	9	1.1	0.9	0.2
414	12	2.3	1.2	0.4
415	11	3.1	1.2	0.7
416	11	1.9	0.9	0.4
417	12	1.2	0.7	0.2
418	11	1.2	0.6	0.3
419	12	1.6	0.8	0.3
422	11	1.9	1.0	0.4
423	12	1.0	0.6	0.2
425	12	1.2	0.5	0.3
426[a]	10	1.0	0.6	0.3
427[a]	9	0.8	0.4	0.2
429[a]	12	2.3	1.4	0.4

[a] Determined by the lead-peroxide candle method.

2.4 HYDROGEN SULFIDE

Hydrogen sulfide (H_2S) sampling stations were located at six sites in the St. Clair River area and at four sites in the Detroit River area. The H_2S was collected on mercuric chloride-impregnated filter tape using an automatic sequential-tape sampler for a 2-hour sampling period. The 2-hour average H_2S concentration was determined by developing the tape with ammonia and then measuring the optical density of the resulting spots with a densitometer.

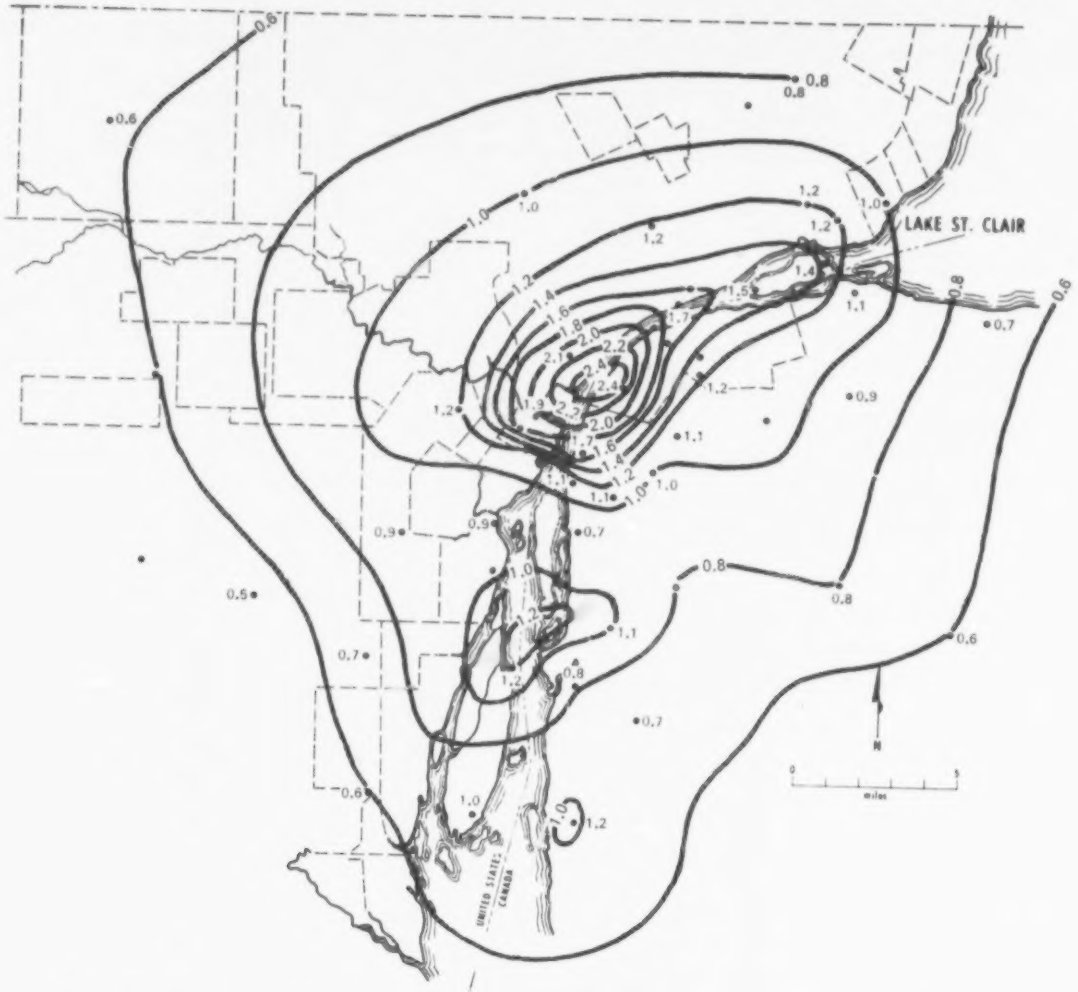

Figure 2-9. Annual average sulfation rates in Detroit - Windsor area (mg SO_3/100 cm^2-day).

The data from Stations 151, 155, 158, 161, and 212 were reported to the nearest 1 ppb, with a minimum reported value of 1 ppb. Data from Stations 202, 303, 310, 408, and 409 were recorded, however, to the nearest 0.1 ppb, with a minimum reported value of 0.1 ppb. This difference in resolution is reflected in the tables.

2.4.1 Port Huron - Sarnia Area

The data obtained in the Port Huron - Sarnia area are summarized in Tables 2-24, 2-25, and 2-26. The highest 2-hour average concentration of 100 ppb and the highest daily average of 9 ppb were recorded at Station 158. The reported perceptible odor levels ranged from 1 ppb to 50 ppb.

Only Stations 303 and 310 (December-February) and 151 (September-November) experienced seasonal average concentrations equal to the perceptible odor thresholds reported.

Table 2-24. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF 2-HOUR AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppb						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≧ stated value:								
		90	75	50	25	10	1			
151	3,652	<1.0	<1.0	<1.0	<1.0	2.0	10.0	50.0	<1.0	2.0
155	3,414	<1.0	<1.0	<1.0	<1.0	<1.0	4.0	30.0	0.4	1.0
158	4,100	<1.0	<1.0	<1.0	<1.0	1.0	4.0	100.0	0.0	3.0
161	3,785	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	11.0	0.0	0.4
303	2,164	<0.1	<0.1	<0.1	<0.4	0.9	4.0	6.6	0.4	0.7
310	2,517	<1.0	<1.0	<1.0	<1.0	1.0	7.0	17.9	0.6	1.0

Table 2-25. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppb						Maximum value	Arithmetic mean
		% of samples ≧ stated value:							
		90	75	50	25	10	1		
151	325	<1.0	<1.0	<1.0	<1.0	2.0	5.0	7.0	<1.0
155	293	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	8.0	0.0
158	357	<1.0	<1.0	<1.0	<1.0	1.0	5.0	9.0	0.0
161	327	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	3.0	0.0
303	190	<0.1	<0.1	0.2	0.4	0.9	3.7	4.0	0.4
310	220	<0.1	<0.1	0.2	0.6	1.6	4.0	4.6	0.6

Table 2-26. SEASONAL VARIATIONS IN HYDROGEN SULFIDE CONCENTRATIONS, 2-HOUR SAMPLES, IN PORT HURON - SARNIA AREA, DECEMBER 1967 THROUGH NOVEMBER 1968

Station number	Arithmetic mean, ppb							
	Number of samples	Dec-Feb	Number of samples	Mar-May	Number of samples	June-Aug	Number of samples	Sept-Nov
151	922	<1.0	1,003	0.0	691	<1.0	1,036	1.0
155	321	<1.0	1,090	0.0	939	0.0	1,065	0.0
158	1,043	0.0	1,068	0.0	1,019	0.0	970	0.0
161	953	0.0	749	0.0	1,017	0.0	1,066	0.0
303	377	1.0	172	0.5	808	0.2	807	0.2
310	253	1.0	607	0.5	973	0.2	684	0.9

2.4.2 Detroit - Windsor Area

Only two stations, 408 and 409, both in the U. S., made a sufficient number of observations to permit the calculation of meaningful statistics. From the data available for the stations with incomplete records, the maximum 2-hour concentration measured at Canadian Station 212 was less than 1 ppb, whereas Station 202 had a maximum 2-hour value of 5.2 ppm.

A statistical summary for Stations 408 and 409 is given in Tables 2-27 and 2-28. Of these two stations, only 408, in the highly industralized River Rouge area experienced a mean concentration of H_2S in excess of 1 ppb.

Table 2-27. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF 2-HOUR AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppb % of samples ≧ stated value: 90	75	50	25	10	1	Maximum value	Arithmetic mean	Arithmetic standard deviation
408	2,804	<0.1	<0.2	<0.6	1.3	3.0	18.7	40.8	1.4	3.3
409	2,383	<0.1	0.1	0.1	0.4	0.8	3.4	10.6	0.3	0.7

Table 2-28. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN DETROIT RIVER STUDY AREA

Station number	Number of samples	Concentration, ppb % of samples ≧ stated value: 90	75	50	25	10	1	Maximum value	Arithmetic mean
408	241	0.2	0.4	0.8	1.6	3.5	9.9	16.6	1.4
409	202	<0.1	<0.1	0.2	0.3	0.7	2.7	3.0	0.4

Table 2-29 shows the statistics for the 2-hour average concentration of H_2S on a seasonal basis.

2.5 CARBON MONOXIDE

Carbon monoxide was not considered from the aspect of transboundary pollution but was included only for completeness of the survey. The only significant source of CO air pollution in the Detroit - Windsor area is the automobile. In the Port Huron - Sarnia area, industrial process losses were responsible for nearly three-fourths of the CO emissions. In city streets, the concentrations of CO commonly reach 10 to 50 ppm or higher, but some distance away the gas concentration drops to barely detectable levels. Thus a few hundred cars in the vicinity of a sampler will produce higher concentrations than will many thousands of cars a mile away. Although the large number of automobiles in Detroit would produce a greater total amount of CO than that found in Windsor, the CO detected in Windsor

Table 2-29. SEASONAL VARIATIONS IN HYDROGEN SULFIDE CONCENTRATIONS, 2-HOUR SAMPLES, IN DETROIT - WINDSOR AREA, DECEMBER 1967 THROUGH NOVEMBER 1968

Sampling period	Station number	Number of samples	Arithmetic mean, ppb	Concentrations, ppb, exceeding 1% of samples	Concentrations, ppb, exceeding 10% of samples
Dec-Feb	408	445	1.8	9.4	4.0
	409	522	0.6	5.1	1.8
Mar-May	408	445	1.1	15.8	2.4
	409	522	0.2	1.3	0.6
Jun-Aug	408	445	1.4	23.7	3.1
	409	522	0.1	1.2	0.5
Sept-Nov	408	445	1.6	23.0	3.0
	409	552	0.3	2.9	0.8

would largely be the result of local rather than Detroit traffic.

2.5.1 Air Quality Criteria

Carbon monoxide is important mainly in relation to health. It has little or no potential for damage to vegetation or materials in conceivable ambient concentrations. The toxic properties of relatively high concentrations of the gas are well known. It is a frequent cause of sudden death in confined spaces. The effects of exposure to the transient levels which occur in city streets or the atmosphere at large are less well known. Relatively low concentrations will cause unpleasant symptoms by interfering with the oxygen transport capacity of the blood. These effects are apparently reversible, but not all medical authorities would agree that there are no harmful sequelae to repeated doses of the gas. Evidence indicates that human responses to low concentrations may include diminished visual acuity and an impaired ability to concentrate.

Criteria for CO are to be published by the U. S. National Air Pollution Control Administration but are not yet available. Some states and cities in the U. S. have set standards. For example, Pennsylvania has adopted an air quality standard of 25 ppm on the basis of 24-hour samples. Ontario regulations, as previously mentioned, allow up to 60 ppm for 1 hour or 15 ppm for 8 hours, irrespective of land use.

2.5.2 Measured Carbon Monoxide

Carbon monoxide concentrations were measured in the Detroit - Windsor area at Station 408 from December 1967 through June 1968, and at Station 208 from June 1968 through November 1968. The measurements were made by continuous-monitoring nondispersive infrared analyzers. Cumulative percent frequency distributions of hourly average CO concentrations for the period of observation are presented in Table 2-30. A concentration of 3.0 ppm was exceeded by 50 percent of the samples at both stations, and 6.7 ppm was exceeded by 10

Table 2-30. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE CARBON MONOXIDE CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm								
		% of samples ≥ stated value:						Maximum value	Arithmetic mean	Arithmetic standard deviation
		90	75	50	25	10	1			
208	1,464	1.5	2.0	3.0	8.0	13.5	15.5	19.0	5.4	4.6
408	3,551	1.0	1.7	3.0	4.5	6.7	13.0	18.0	3.6	2.7

percent of the samples at Station 408; 13.5 ppm was exceeded by 10 percent of the samples at Station 208.

Carbon monoxide concentrations within urban areas show large variations, depending on the location of the sampling station and the period of observation. Consequently, the CO concentration data given in Table 2-30 cannot be considered representative of Detroit and Windsor. Rather they are only measurements for particular locations over specific periods of time. For comparison, the average annual concentrations of CO measured at the Continuous Air Monitoring Program (CAMP) stations of the U. S. National Air Pollution Control Administration are given in Table 2-31.

Table 2-31. AVERAGE ANNUAL CONCENTRATIONS OF CARBON MONOXIDE IN SEVERAL CITIES IN THE UNITED STATES

(ppm)

City	Year				
	1962	1963	1964	1965	1966
Chicago	--	8.3	12.1	17.1	12.5
Cincinnati	--	7.0	6.1	4.0	4.9
Denver	--	--	--	7.2	7.9
Philadelphia	--	--	7.1	8.1	6.8
San Francisco	--	5.4	5.2	--	--
St. Louis	--	--	6.3	6.5	5.8
Washington	5.3	6.7	5.7	3.7	3.3

2.6 HYDROCARBONS

Low-boiling-point aliphatic and aromatic HC occur in the atmosphere as emissions from automobile crankcases and exhausts, evaporative losses from gasoline handling and storage, and process losses from industries such as chemical plants and petroleum refineries. The several refineries and chemical plants in Sarnia were considered possible major point sources of HC, but, relatively speaking, such sources were not as significant in the Detroit - Windsor area. In the Detroit - Windsor area the automobile was the most significant source of HC.

Hydrocarbon concentrations were measured in both areas, however, using continuously recording flame-ionization analyzers. Measurements were given as one-hour averages.

2.6.1 Air Quality Criteria

The chief significance of HC as air pollutants lies in their capability to react with NO_x in the presence of sunlight to produce photochemical pollution characterized by oxidants. Hydrocarbons, in concentrations that conceivably can occur in the ambient atmosphere, have not been reported as being responsible for direct health effects. Accordingly, health effects do not form the basis for air quality criteria.

With the exception of ethylene, to which some plant species are particularly susceptible, HC pose no known threat to vegetation. In regard to ethylene, however, orchids, for example, cannot safely be exposed to concentrations in excess of 0.01 ppm for 24 hours or 0.3 ppm for 1 hour. Other species such as roses can tolerate concentrations several thousand times greater. Ethylene was not specifically measured in the study.

Hydrocarbons also are not considered to be responsible for damage to materials except indirectly through the formation of oxidants.

2.6.2 Measured Hydrocarbons

Hydrocarbon concentrations were measured at three locations in the Port Huron - Sarnia area and one location in the Detroit - Windsor area.

2.6.2.1 Port Huron - Sarnia Area - Hourly average HC concentrations measured in the Port Huron - Sarnia area are summarized in Table 2-32; corresponding daily average values are given in Table 2-33. An hourly average of 5.0 ppm was equaled or exceeded by 1 percent of the observations and a daily average of 3.0 ppm was equaled or exceeded by 1 percent of the observations. Hourly and daily mean values ranged from 0.5 to 0.7 ppm. As shown in Table 2-34, there was little change in average concentrations with seasons.

Table 2-32. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE HYDROCARBON CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≥ stated value:								
		90	75	50	25	10	1			
151	7,338	<0.1	<0.1	<0.1	0.5	1.5	5.0	15.0	0.5	1.1
155	5,844	<0.1	<0.1	0.5	1.0	2.0	5.0	35.0	0.7	1.2
158	8,107	0.1	<0.1	<0.1	0.5	1.5	6.0	40.0	0.6	1.5

2.6.2.2 Detroit - Windsor Area - The measurements of HC concentrations made at the single station in the Detroit - Windsor area are summarized in Tables 2-35 and 2-36. An hourly average concentration of 10.8 ppm was equaled or exceeded by 1 percent of the samples, and a daily average concentration of 9.1 ppm was equaled or exceeded by 1 percent of the samples.

Table 2-33. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE HYDROCARBON CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≥ stated value:							
		90	75	50	25	10	1		
151	346	<0.1	<0.1	0.3	0.7	1.2	3.2	4.4	0.5
155	265	<0.1	0.1	0.5	1.0	1.5	3.0	4.7	0.7
158	356	<0.1	0.1	0.4	0.7	1.4	3.8	5.8	0.6

Table 2-34. SEASONAL HYDROCARBON CONCENTRATIONS, 1-HOUR SAMPLES, IN PORT HURON - SARNIA AREA, DECEMBER 1967 THROUGH NOVEMBER 1968

Sampling period	Station number	Number of samples	Arithmetic mean, ppb	Concentrations, ppm, exceeding 1% of samples	Concentrations, ppm, exceeding 10% of samples
Dec-Feb	151	1,875	0.6	5.0	2.0
	155	--	--	--	--
	158	1,939	0.4	3.5	1.0
Mar-May	151	1,883	0.5	4.0	1.5
	155	1,905	1.0	6.0	2.5
	158	2,024	0.6	6.0	1.5
Jun-Aug	151	1,938	0.5	6.0	1.5
	155	1,888	0.8	5.0	2.0
	158	2,028	0.8	8.0	2.0
Sept-Nov	151	1,642	0.5	5.0	1.5
	155	2,051	0.4	3.0	1.5
	158	2,116	0.5	5.0	1.2

Table 2-35. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE HYDROCARBON CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≥ stated value:								
		90	75	50	25	10	1			
408	3,189	0.9	1.5	2.4	3.7	5.4	10.8	16.8	2.9	2.1

Table 2-36. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE HYDROCARBON CONCENTRATIONS IN DETROIT RIVER STUDY AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≥ stated value:							
		90	75	50	25	10	1		
408	156	1.1	1.6	2.6	3.6	4.7	9.1	9.1	2.8

Concentration measurements were made at the Detroit station during only one complete quarter and portions of two other quarters of the year, thus, seasonal statistics are not available.

2.7 OXIDANTS

Oxidants, as a class of air pollutants, are usually formed by photochemical reactions in mixtures of NO_x and unsaturated HC. Ozone is often a major constituent of the class. Other gases such as chlorine, however, are oxidants and may be emitted directly to the atmosphere from chemical process operations.

In large urban areas or cities, the occurrence of oxidants can be linked to the density of automobiles, since the latter are the main source of HC and are also a major contributor of NO_x emissions.

Point sources cannot be identified for oxidants formed photochemically because the basic constituents have usually dispersed before and during the reaction process; therefore, it was not a purpose of the survey to try to attribute oxidant pollution to specific causes.

2.7.1 Air Quality Criteria

Oxidants in the atmosphere have several undesirable properties. At a certain level, usually considered to be about 0.15 ppm expressed as ozone, eye irritation becomes noticeable. Such pollution also affects human performance in other respects, but evidence concerning long-term or irreversible health effects is not substantial or conclusive.

Many plant species are also subject to damage by oxidant pollution and some types are especially sensitive. Ozone itself adversely affects some crops in concentrations from about 0.05 ppm. Damage can be rapid in concentrations of a few tenths of a part per million. Other oxidants, particularly peroxyacetyl nitrate, are even more damaging than ozone. Peroxyacetyl nitrate was not specifically measured in the survey, but plants were examined according to the effects that this and other phytotoxic substances produce.

Material damage is also greatly enhanced by oxidants. Rubber is particularly susceptible, but textiles and metals are also affected. Damage to property has been reported with oxidant concentrations of a few parts per 100 million.

Air quality criteria for photochemical oxidants[4] have only recently been published by the U. S. National Air Pollution Control Administration, and few areas have adopted standards as yet. They have been in use in California for many years, chiefly as indicators of alert conditions, but not as desirable air quality. The Ontario standards have been presented in the introduction to Section 2.

2.7.2 Measured Oxidants

Total oxidant concentrations were measured at six locations in the Port Huron - Sarnia area and at three locations in the Detroit - Windsor area. Measurements were made with continuous-monitoring coulometric type analyzers except at Station 208 where a colorimetric technique was used.

2.7.2.1 Port Huron - Sarnia Area - All oxidant concentrations measured in the Port Huron - Sarnia area were obtained on the Canadian side of the St. Clair River. Hourly average values for the six stations are summarized in Table 2-37.

Table 2-37. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE TOTAL OXIDANT CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≧ stated value:								
		90	75	50	25	10	1			
151	7,425	<0.01	<0.01	0.01	0.02	0.02	0.06	0.11	0.01	0.01
152	1,419	<0.01	<0.01	0.01	0.02	0.03	0.06	0.11	0.01	0.01
155	6,113	<0.01	<0.01	0.01	0.02	0.03	0.06	0.15	0.02	0.01
158	6,109	<0.01	<0.01	0.01	0.02	0.02	0.05	0.09	0.01	0.01
161	7,424	<0.01	<0.01	0.01	0.02	0.03	0.07	0.11	0.02	0.01
163	4,521	<0.01	<0.01	<0.01	0.02	0.02	0.05	0.11	0.01	0.01

Only one station, 155, had a maximum 1-hour average concentration value as high as the maximum allowed by the Ontario standards.

Maximum values of daily (24-hour) average concentrations were 0.05 ppm or less at all stations (Table 2-38). This value is well below the 0.10 ppm maximum concentration allowed by the Ontario Air Quality Standards.

2.7.2.2 Detroit - Windsor - Total oxidant concentration measurements made in the Detroit - Windsor area are summarized as hourly averages in Table 2-39 and as daily (24-hour) averages in Table 2-40. It should be noted that these are based on short periods of observation.

The maximum 1-hour average total oxidant concentration at Station 208 exceeded the limit specified by Ontario, and the corresponding maximum at Station 420 was close to that limit. Similarly, the 0.13 ppm 24-hour average concentration at Station 208 exceeded the Ontario limit.

2.8 NITROGEN OXIDES

Nitrogen oxides are sometimes emitted into the atmosphere from chemical plants, but they are also formed in combustion and other high-temperature

Table 2-38. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE TOTAL OXIDANT CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≧ stated value:							
		90	75	50	25	10	1		
151	342	<0.01	<0.01	0.01	0.01	0.02	0.04	0.04	0.01
152	60	<0.01	<0.01	0.01	0.02	0.02	-	0.03	0.01
155	267	<0.01	<0.01	0.02	0.02	0.03	0.04	0.05	0.01
158	268	<0.01	<0.01	0.01	0.02	0.02	0.04	0.05	0.01
161	324	<0.01	<0.01	0.01	0.02	0.03	0.05	0.05	0.02
163	203	<0.01	<0.01	<0.01	0.01	0.02	0.03	0.04	0.01

Table 2-39. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE TOTAL OXIDANT CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≧ stated value:								
		90	75	50	25	10	1			
208	584	<0.01	<0.01	0.01	0.06	0.09	0.13	0.20	0.03	0.04
220	375	<0.01	<0.01	0.01	0.01	0.02	0.03	0.04	0.01	0.01
420	1,161	<0.01	<0.01	0.03	0.04	0.06	0.09	0.12	0.03	0.02

Table 2-40. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE TOTAL OXIDANT CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≧ stated value:							
		90	75	50	25	10	1		
208	29	<0.01	<0.01	0.08	0.02	0.05	-	0.13	0.01
220	20	<0.01	<0.01	0.01	<0.01	0.01	-	0.02	0.01
420	55	0.02	0.02	0.05	0.03	0.03	-	0.07	0.03

operations as the result of the direct combination of atmospheric nitrogen and oxygen. Motor vehicles are major contributors. In the survey area, there were no significant direct chemical process sources of NO_x, and the presence of these compounds was attributed only to high temperature reactions. Stationary sources of NO_x are located in both countries, although in the Port Huron - Sarnia area, the greater part of the emissions occurred in Sarnia, whereas in the Detroit - Windsor area, the bulk of the NO_x was generated in Detroit. It was not expected that transboundary flow of NO_x would be detected because it was recognized that any transboundary effects would be masked by discharges from motor vehicles. In the vicinity of heavy traffic, NO_x concentrations may reach or exceed 1 ppm, but generally, atmospheric levels of only a few parts per 100 million are found. It is inevitable that NO_x will be transported across the boundary, but the transported gases can be expected to be insignificant compared to the amount that is produced locally. Consequently, inclusion of NO_x in the survey was mainly for completeness and not as a transboundary indicator.

2.8.1 Air Quality Criteria

Air quality criteria for NO_x will be published by the U. S. National Air Pollution Control Administration, but are not yet available. The chief significance of NO_x as pollutants is their reaction with HC in the production of photochemical pollution. Nitrogen dioxide, however, is also a pulmonary irritant. So far, NO_x in urban pollution have not been implicated as causes of adverse health effects, but it would be prudent to treat them at least as seriously as SO_2. Combinations of the two might very reasonably be treated at least additively as causes of respiratory irritation.

Nitrogen oxides, especially the dioxide, are also harmful to vegetation, but usually to a lesser extent than SO_2. Nitrogen dioxide, as a corrosive agent, is also capable of damaging materials, but little information is available on the effects of different levels of the gas. Still less is known about possible harmful effects of nitrogen monoxide; in any case, it normally oxidizes to the dioxide in the atmosphere.

Air quality standards for NO_x have not been adopted in many areas. These oxides are, however, included in the Ontario regulations that were presented earlier in this section.

2.8.2 Nitrogen Oxide Measurements

Nitrogen oxides were measured at Stations 151 and 152 in the Port Huron - Sarnia area and at Stations 202 and 208 in the Detroit - Windsor area. All measurements were made with continuous monitoring instruments employing Saltzman reagent.

2.8.2.1 Port Huron - Sarnia Area - Measurements of hourly average and daily (24-hour) average concentrations of NO_x in the Port Huron - Sarnia area are summarized in Tables 2-41 and 2-42. The maximum hourly and maximum daily average concentrations at Station 151 exceeded the limiting values of 0.20 ppm and 0.10 ppm, respectively, of the Ontario regulations. Station 152 measured no concentrations exceeding the limits in the regulations.

Table 2-41. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE NITROGEN OXIDES CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm % of samples ≥ stated value:						Maximum value	Arithmetic mean	Arithmetic standard deviation
		90	75	50	25	10	1			
151	7,666	0.01	0.02	0.03	0.06	0.10	0.30	0.80	0.05	0.06
152	1,541	<0.01	0.01	0.01	0.02	0.04	0.07	0.16	0.02	0.02

Table 2-42. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE NITROGEN OXIDES CONCENTRATIONS IN PORT HURON - SARNIA AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≥ stated value:							
		90	75	50	25	10	1		
151	342	0.01	0.02	0.03	0.05	0.08	0.12	0.15	0.04
152	67	0.01	0.01	0.01	0.02	0.03	-	0.05	0.02

2.8.2.2 Detroit - Windsor Area - As is shown in Tables 2-43 and 2-44, which summarize the NO_x concentrations measured in the Detroit - Windsor area, neither of the two stations had maximum hourly average or daily average concentrations approaching the limits set by Ontario.

Table 2-43. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF HOURLY AVERAGE NITROGEN OXIDES CONCENTRATION IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean	Arithmetic standard deviation
		% of samples ≥ stated value:								
		90	75	50	25	10	1			
202	1,458	<0.01	0.01	0.02	0.02	0.03	0.04	0.11	0.02	0.01
208	1,801	0.01	0.02	0.02	0.04	0.05	0.09	0.12	0.03	0.02

Table 2-44. CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE NITROGEN OXIDES CONCENTRATIONS IN DETROIT - WINDSOR AREA

Station number	Number of samples	Concentration, ppm						Maximum value	Arithmetic mean
		% of samples ≥ stated value:							
		90	75	50	25	10	1		
202	75	<0.01	0.01	0.02	0.02	0.03	-	0.03	0.02
208	112	0.01	0.02	0.02	0.03	0.04	0.08	0.08	0.03

2.9 ODORS

Volatile substances which evoke an olfactory response, usually objectionable, but which are not necessarily identifiable as individual chemical compounds are classified as odorous substances. Although it has a strong and unpleasant odor, H_2S is usually considered specifically and not as a member of the general class. This is largely because H_2S can be readily measured quantitatively in the concentrations which produce barely detectable olfactory response. In some instances, the odor-producing substance may be well known, but techniques are not available for measuring it in the extremely low concentrations at which it occurs in the atmosphere. For example, some complaints made at a public hearing in Port Huron apparently arose because of trimethylamine emissions from one plant. No chemical or other technique could be devised to measure continuously the minute amounts of this compound which may have occurred in the atmosphere during the survey. In such cases, recourse must be made to human olfactory responses. This technique was used in the survey described here, and reliance was placed upon the subjective reactions of the survey staff and volunteers.

2.9.1 Air Quality Criteria

Odors which fall into the general category discussed above rarely, if ever, have any direct effect upon health. They are, however, aesthetically distasteful and may in fact cause somatic illness because of their objectionable properties. This response often can be attributed indirectly to the apprehension many persons might have concerning the presence of any unknown constituent in the atmosphere. So far, no criteria have been established or standards set for this type of odor. Odors are not considered to cause vegetation or property damage.

2.9.2 Odor Survey

Odors from industrial operations have been a source of complaints by local residents along the bank of the St. Clair River from the cities of Port Huron and Sarnia south to Marine City and Sombra. The identification of specific industrial plants or groups of plants as sources of odors has been inferred from the nature of the odors, wind directions, and chronology. Thus the initial complaints of a "dead fish" odor in Marine City, Michigan, and Sombra, Ontario, were registered immediately following the opening of the Chinook Chemicals plant south of Sombra. Similarly, the halogen or gasoline odors in Port Huron that occur with east to south winds are circumstantially associated with the petroleum refineries south of Sarnia.

In order to obtain data on the frequency of occurrence and intensity of odors, investigators patrolled the route between Port Huron and Algonac, Michigan, between August and December 1968. The patrols were usually made during the early morning or late afternoon when odors could be expected to be strongest because of low rates of atmospheric dispersion. The investigators used a scentometer to classify the intensity of the odor on a scale of 0 to 4. The 0 classification represents an odor that can be smelled without using the scentometer, and 1 through 4 indicate increasingly intense odors. Wind direction at the place where odor was measured was determined by observing the path of a helium-filled free balloon; wind speed at that location was measured by a portable anemometer.

Since the odor problem in Marine City - Sombra could apparently be attributed to one offending source, results of the survey in that region were examined separately from the results of the survey of the region between Port Huron and Marysville.

2.9.2.1 Port Huron - Marysville Sector - The odors observed in the Port Huron area were considered by the investigators to be a mixture caused by petroleum refining and petroleum-related organic chemical manufacturing. Odors may have come not only from process losses but from safety flares used by the chemical plants and refineries to oxidize dangerous compounds to prevent their release into the atmosphere. The flares, which at times provide incomplete combustion, were noted to be sooty and black. Records of the investigators showed detections of odors on 18 of the 27 patrols in the Port Huron area. Fifteen of the detections showed a strength of 0, two showed a strength of 1, and one showed a strength of 2. In each case of odor detection, the wind was blowing from the sector east through south. On one patrol, an odor was detected adjacent to the Chrysler Marine Plant south of Marysville. This was classified by the investigator as a paint odor.

From mid-October through the end of November 1968, four interested residents of Port Huron maintained records of their assessment of the odor problem in their neighborhoods. Three of these observers lived in the southern portion of Port Huron, which is close to the river and north and slightly west of the chemical and refinery facilities south of Sarnia. The other observer lived in the northern section of the city, not far from a cement plant and a paper mill. Odors reported ranged from at least a slightly objectionable odor every day of the 7-week period to odors on only 18 of the 49 days. In the latter case, all except two of the reported odors were classified as severe. The records of the observer who reported odors on every day included wind direction estimates; very objectionable odors were reported only when winds were easterly or southerly, except on one occasion when a very objectionable odor was reported with a north wind.

2.9.2.2 Marine City Sector - Many complaints have been registered in the Marine City, Michigan, and Sombra, Ontario, area because of a malodor attributed to the Chinook Chemical Company south of Sombra.

Odors were detected in the Marine City - Sombra area on 13 occasions during the 33 patrols by odor investigators during August and September 1968. Seven of these odor detections occurred in the immediate vicinity (within one mile) of the Chinook Chemical Company facilities. One of these odors was recorded as a scentometer strength of 2, one as a strength of 1, and all others as a strength of 0. The remaining six odor detections, not in the immediate vicinity of the chemical plant, were also a strength of 0.

Five interested residents of Marine City, Michigan, maintained records of odor occurrences in their neighborhoods during the 7-week period from mid-October through the end of November 1969. Odors were reported by one or more of these observers on 21 of the 48 days. All five observers reported the occurrence of odors on only one day. The odors noted were attributed to the Chinook Chemical Company plant, except on one occasion when one of the two observers noting the odor recorded that it was "definitely not Chinook".

Records of the Marine City municipal government show that citizens' complaints about odors increased from an average of about two per month during the last half of 1966 to more than three per month during the first half of 1968. These complaints started in June of 1966, approximately coinciding with the opening of the Chinook Chemical Company plant in May. On approximately 20 percent of the days when complaints were filed, the Chinook plant experienced equipment failure or breakdowns that might have resulted in the release of effluents.

2.10 EFFECTS ON MATERIALS

The Effects Package was used to estimate effects of air pollution on selected materials at eleven sites in the study area. The Effects Package is a static sampling device that contains fourteen components with which to monitor specific pollutants and/or their material effects.[5] The monitoring components used are: steel and zinc plates, various types of dyed fabrics, rubber strips, nylon hose, silver plates, sulfation candles, sticky paper, and dustfall buckets. The data obtained were compared to U. S. National Air Pollution Control Administration Interstate Surveillance Project (ISP) data, which are summarized in Table 2-45. Effects Packages for the ISP are located at 270 stations in approximately 85 interstate and international population areas throughout the U. S.

The Hennepin, Illinois, station was used as a background clean air station because its climatic conditions are similar to those of the study area. Results from Effects Packages in Cincinnati, Buffalo, Philadelphia, and Chicago are included for comparison.

2.10.1 Metal Corrosion

Annual and quarterly average zinc corrosion rates and annual steel corrosion rates measured during the study are shown in Table 2-46. Highest zinc corrosion rates occurred at Stations 429 and 400, where the rates measured fell in the 90th and 75th percentiles of ISP data, respectively. The rate at Station 429 was approximately five times that at Hennepin, Illinois. Rates reported at Stations 429 and 400 were lower than at Buffalo and Chicago but higher than at Cincinnati and Philadelphia.

Highest annual and quarterly average steel corrosion rates occurred at Station 305. The annual rate was in the 90th percentile and the quarterly rate in the 75th percentile of the ISP data at four of the seven other stations reporting. The quarterly average steel corrosion rate was in the 75th percentile at six of ten reporting stations. In general, the rates reported by all stations were higher than those, for the same period, in Cincinnati and Chicago, but far lower than those in Buffalo.

2.10.2 Color Fading of Dyed Fabrics

Dye fading was measured with standard dyed fabrics, Numbers 3 and 5, which are sensitive to NO_x and ozone, respectively (Table 2-47). Color fading rates of the Number 3 fabric fell in the 75th percentile of ISP data at three (400, 429, 202) of 11 stations reporting (Table 2-45). Color fading rates of the Number 5 fabric fell in the 75th percentile of ISP data at three (427, 154, 217) of the 11 stations.

The color fading rates of the Number 3 fabric at all stations were lower than those reported in Chicago, Cincinnati, Philadelphia, and Buffalo. In contrast, the color fading rates of the Number 5 fabric at all stations were higher than reported in those other cities.

2.10.3 Silver Tarnishing

Silver tarnishing is caused to some degree by a number of pollutants, but H_2S is usually the primary causative agent.

No stations reported silver tarnishing rates higher than the 50th percentile of ISP data (Tables 2-45, 2-48) although four (Stations 400, 429, 301, 305) reported data twice that of background (Station 56).

Table 2-45. CUMULATIVE FREQUENCY DISTRIBUTIONS OF AIR POLLUTION EFFECTS, INTERSTATE SURVEILLANCE PROJECT DATA, 1968

Measurement	Exposure period	Number of samples	Minimum	% of samples less than stated values:					Maximum
				10	25	50	75	90	
Metal corrosion rates, µm/yr									
Zinc	1 year	216	0.1	0.64	1.05	1.87	3.53	4.93	15.4
Steel	1 year	204	0.0	6.0	16.0	29.0	42.0	53.0	88.0
Steel	3 months	874	0.0	3.0	11.0	38.0	67.0	89.0	194.0
Dye fading, Judd units									
Color change, type 3 dyed fabrics	3 months	822	6.8	16.2	19.7	23.8	31.0	41.1	62.8
Color change, type 5 dyed fabrics	3 months	796	2.3	6.1	8.0	11.0	13.4	15.2	22.6
Silver tarnishing, reflectance, % loss	1 month	2,835	0.0	22.0	36.0	55.0	75.0	85.0	100.0
Nylon deterioration, total number of defects	3 months	921	0.0	0.0	0.0	0.0	1.0	5.0	255.0
	1 month	2,849	0.0	0.0	0.0	0.0	0.0	2.0	233.0
Rubber deterioration, average crack depth, µm	1 week	11,349	0.0	0.0	0.0	48.0	144.0	220.0	683.0

Table 2-46. CORROSION RATES IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS; DATA FOR FIVE UNITED STATES CITIES GIVEN FOR COMPARISON

Station number or location	Starting date	Corrosion rates, μm/yr		
		Zinc	Steel	Steel[a]
400	5-02-66	3.7	51	75
429	5-03-66	5.7	--	77
409	9-08-67	Void	48	64
426	10-04-67	2.8	37	51
427	9-27-67	---	40	47
202	2-07-68	2.3	--	--
301	9-13-67	3.3	30	73
305	9-13-67	2.6	56	84
154	2-28-68	1.3	49	76
158	2-28-68	1.4	47	77
217	2-28-68	4.1	--	31
Hennepin, Ill.	6-21-66	1.1	31	41
Cincinnati, Ohio	1-19-66	1.9	18	25
Philadelphia, Pa.	1-13-66	3.1	--	71
Buffalo, N. Y.	1-27-66	7.1	88	128
Chicago, Ill.	1-31-66	5.2	31	50

[a] Based on average values for 3 months.

The silver tarnishing rates reported throughout the study area compared very closely with those reported in Cincinnati but were somewhat lower than those in Philadelphia, Buffalo, and Chicago.

2.10.4 Nylon Deterioration

Nylon damage is associated with acid mist in the atmosphere. Although nylon damage was observed at Stations 400 in January, 429 in August, and 217 in July (Table 2-49), the occurrences are far too few to be considered a serious problem. The nylon damage reported at all stations in the area was far less than that reported at Philadelphia and Chicago during the same period.

2.10.5 Rubber Deterioration

Rubber deterioration is associated with the presence of ozone in the atmosphere. Its rates throughout the study area (Table 2-50) fall within the 50th percentile of ISP data (Table 2-45). These rates are lower than those at the control station in Hennepin, Illinois. The rubber deterioration reported in the area was slightly higher than that reported in Chicago, Philadelphia, Buffalo, and Cincinnati.

Table 2-47. FADING OF DYED FABRICS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS; DATA FOR FIVE UNITED STATES CITIES GIVEN FOR COMPARISON

Station number or location	Starting date	Number of quarterly samples	Color change, Judd units (ΔE)	
			Type 3, NO_x	Type 5, Ozone
400	5-02-66	4	37.6	9.6
429	5-03-66	3	33.5	11.1
409	9-08-67	3	26.5	11.3
426	10-04-67	3	27.4	11.5
427	9-27-67	2	21.4	14.0
202	2-07-68	2	31.4	9.7
301	9-13-67	4	24.1	12.1
305	9-13-67	4	23.4	12.0
154	2-28-68	3	24.7	14.0
158	2-28-68	3	21.9	11.8
217	2-28-68	2	28.1	13.6
Hennepin, Ill.	6-21-66	3	17.5	11.9
Cincinnati, Ohio	1-19-66	4	34.8	9.3
Philadelphia, Pa.	1-13-66	4	41.3	8.5
Buffalo, N. Y.	1-27-66	4	39.2	5.9
Chicago, Ill.	1-31-66	4	50.7	4.0

2.10.6 Summary

When data from this study are compared with the ISP data, it can be concluded that the major materials problem in the International Joint Commission Detroit - St. Clair River study area is the corrosion of metals (steel and zinc). Dye fading due to NO_x and ozone, although observed, is not unusually great. No major problems were noted in nylon deterioration, silver tarnishing, or rubber deterioration, although levels were usually above those at the background clean station.

2.11 EFFECTS OF AIR POLLUTION

Air pollution damage to vegetation is important not only for the economic losses it causes agriculture, but also because vegetation damage is a forewarning of air pollution problems that might effect man and his environment.

Plant varieties have been used extensively in monitoring programs as indicators of air pollution.[6-10] Their usefulness in this capacity is based on the sensitivity of selected plant species to specific air pollutants.

Prior to 1969, no published information indicated that air pollution might be causing damage to vegetation in the Port Huron - Sarnia and Detroit - Windsor

Table 2-48. SILVER TARNISHING IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS; DATA FOR FIVE UNITED STATES CITIES GIVEN FOR COMPARISON

Station number or location	Starting date	Number of monthly samples	Reflectance, % loss
400	5-02-66	12	73
429	5-03-66	12	71
409	9-08-67	11	62
426	10-04-67	11	59
427	9-27-67	10	46
202	2-07-68	9	69
301	9-13-67	12	70
305	9-13-67	12	52
154	2-28-68	10	64
158	2-28-68	11	66
217	2-28-68	10	50
Hennepin, Ill.	6-21-66	12	34
Cincinnati, Ohio	1-19-66	12	55
Philadelphia, Pa.	1-13-66	11	81
Buffalo, N. Y.	1-27-66	11	88
Chicago, Ill.	1-31-66	10	77

Table 2-49. NYLON DAMAGE IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS; DATA FOR FIVE UNITED STATES CITIES GIVEN FOR COMPARISON

Station number or location	Starting date	Number of monthly samples	Total number of defects
400	5-02-66	12	2
429	5-03-66	12	2
409	9-08-67	11	0
426	10-04-67	12	0
427	9-27-67	11	0
202	2-07-68	10	0
301	9-13-67	12	0
305	9-13-67	12	0
154	2-28-68	9	0
158	2-28-68	10	0
217	2-28-68	9	1
Hennepin, Ill.	6-21-66	12	0
Cincinnati, Ohio	1-19-66	12	0
Philadelphia, Pa.	1-13-66	12	53
Buffalo, N. Y.	1-27-66	11	2
Chicago, Ill.	1-31-66	12	26

Table 2-50. RUBBER DETERIORATION IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS; DATA FOR FIVE UNITED STATES CITIES GIVEN FOR COMPARISON

Station number or location	Starting date	Number of samples	Average crack depth, μm
400	5-02-66	52	73
429	5-03-66	47	73
409	9-08-67	39	32
426	10-04-67	52	70
427	9-27-67	32	142
202	2-07-68	36	143
301	9-13-67	44	58
305	9-13-67	46	56
154	2-28-68	43	60
158	2-28-68	43	55
217	2-28-68	36	126
Hennepin, Ill.	6-21-66	46	110
Cincinnati, Ohio	1-19-66	50	58
Philadelphia, Pa.	1-13-66	45	62
Buffalo, N. Y.	1-27-66	46	40
Chicago, Ill.	1-31-66	51	21

study areas. This report is an attempt to identify some of the toxicants present in those areas and to evaluate the effects on vegetation of the pollutants found in the air at Port Huron - Sarnia and Detroit - Windsor. The presence of these toxicants indicated by changes in the leaves of selected, sensitive plants grown in the study areas.

2.11.1 Selective Vegetation Study

2.11.1.1 Methodology - To obtain information on air pollution effects on vegetation in the area, a study was undertaken to assess damage on plant species. Selective vegetation was cultured hydroponically in vermiculite in exposure shelters at six locations from May 6 through July 17, 1968, at Belle Isle Park, Grosse Ile, Detroit, and Port Huron, Michigan, and in Windsor and Sarnia, Ontario, as shown in Figure 2-10.

Six plant shelters (6 feet in diameter by 7 feet high) were made from translucent fiberglass panels with aluminum frames, and then erected on wooden platforms. Three vents in the sides near the bottom admitted ambient air and an exhaust fan in the roof provided one complete air change per minute. A control shelter with activated charcoal filters was installed at the Grosse Ile site.

Tobacco W3, pinto bean, geranium, petunia, begonia, and gladiolus were grown in vermiculite hydroponically in 4-inch pots under controlled conditions in

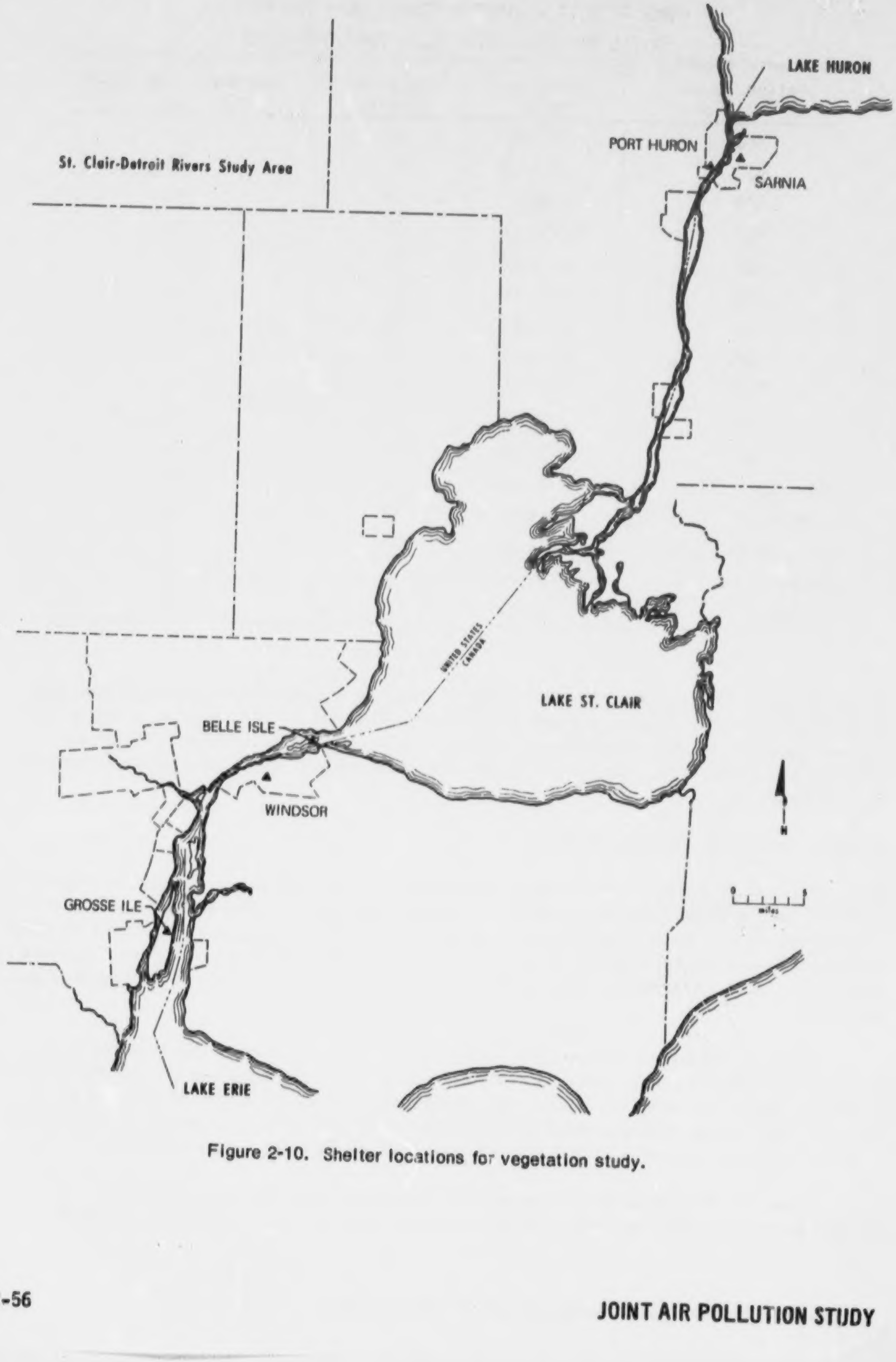
LAKE HURON
PORT HURON
SARNIA
St. Clair-Detroit Rivers Study Area
UNITED STATES
CANADA
LAKE ST. CLAIR
BELLE ISLE
WINDSOR
N
miles
GROSSE ILE
LAKE ERIE

Figure 2-10. Shelter locations for vegetation study.

the laboratory. Seedlings of selected plants were transported into vermiculite in 8-inch pots and placed in shallow trays containing a prepared nutrient solution.

Vegetation was examined for leaf injury when the plants were tended, two to three times each week. Accumulation of leaf injury and suppression of growth were summarized after the first 5 weeks, the second 5 weeks, and for the entire 10-week study period.

2.11.1.2 Results

2.11.1.2.1 Ozone and sulfur dioxide. The plants exhibited SO_2, fluoride, ozone (O_3), and PAN-type damage, as well as chlorosis and generalized growth suppression.

Tables 2-51 and 2-52 summarize leaf damage on the selective vegetation. Data are shown for two 5-week periods, from May 6 through June 6 and from June 7 to July 17, 1968. Both the type and amount of damage are listed.

Table 2-51. DAMAGE TO PLANT VARIETIES DURING THE 5-WEEK PERIOD, MAY 6 THROUGH JUNE 6, 1968

Plant	Grosse Ile	Windsor	Belle Isle	Port Huron	Sarnia
Tobacco	O_3 (M)[a]	$O_3 \times SO_2$[b] (E)	O_3 (E)	O_3 Acid mist (M)	$O_3 \times SO_2$ (E)
Pinto bean	O_3 Suppression (M)	$O_3 \times SO_2$ Suppression (M)	PAN Suppression (M)	Suppression (T)	O_3 PAN (M)
Petunia	Suppression (T)	$O_3 \times SO_2$ Suppression (M)	Suppression (M)	Suppression (T)	Suppression
Begonia	Suppression (T)	O_3 (M)	O_3 (M)	Suppression (T)	Chlorosis (T)
Geranium	Chlorosis (T)	Chlorosis (M)	Chlorosis (M)	Chlorosis (T)	Chlorosis Pigmentation (M)

[a] Letters indicate extent of damage:
T (trace) = 0 to 5 percent of leaf area damaged.
M (moderate = 5 to 25 percent of leaf area damaged.
E (extensive) = 25 to 50 percent of leaf area damaged.

[b] $O_3 \times SO_2$ indicates synergism between ozone and sulfur dioxide.

When the type of injury is specific to a certain pollutant, the pollutant responsible is listed. If the type of injury is nonspecific, however, it is classified according to type of damage, such as chlorosis. Figures 2-11 and 2-12 show the levels of ozone and SO_2 in Sarnia on selected dates. Figures 2-13 and 2-14 show the levels in Windsor on selected dates. These levels of pollutants correspond with the

Table 2-52. DAMAGE TO PLANT VARIETIES DURING THE 5-WEEK PERIOD, JUNE 7 THROUGH JULY 17, 1968

Plant	Grosse Ile	Windsor	Belle Isle	Port Huron	Sarnia
Tobacco	O_3 (E)[a]	$O_3 \times SO_2$[b] (E)	$O_3 \times SO_2$ (E)	$O_3 \times SO_2$ Acid mist (E)	$O_3 \times SO_2$ Acid mist (S)
Pinto bean	O_3 (M)	O_3 (M)	O_3 PAN (M)	O_3 (M)	O_3 PAN SO_2 (E)
Petunia	Chlorosis (M)	O_3 (E)	Oxidant (E)	Chlorosis (M)	O_3 Chlorosis (S)
Begonia	O_3 (M)	O_3 (E)	Oxidant (E)	$O_3 \times SO_2$ Chlorosis (M)	O_3 Chlorosis (S)
Geranium	Chlorosis (M)	Chlorosis (E)	Oxidant (E)	Chlorosis (M)	Chlorosis (E)

[a] Letters indicate extent of damage:

T (trace) = 0 to 5 percent of leaf area damaged.
M (moderate) = 5 to 25 percent of leaf area damaged.
E (extensive) = 25 to 50 percent of leaf area damaged.
S (severe) = >50 percent of leaf area damaged.

[b] $O_3 \times SO_2$ indicates synergism between ozone and sulfur dioxide.

severity of damage that developed on Tobacco W3 in plant shelters. Work done by the National Air Pollution Control Administration in Cincinnati[11] indicated that identical injury was produced with levels of SO_2 as low as 0.1 ppm when combined with 0.03 ppm O_3. Published information[12] indicated that SO_2 concentrations from 0.05 to 0.25 ppm will react synergistically with O_3 to produce moderate to severe injury on sensitive plants. This reaction provides good evidence that O_3 and SO_2 combined to meet the injury threshold of leaf tissue and caused the damage.

In the absence of measured SO_2 and O_3 data, sulfation and rubber cracking data were used to approximate the average concentrations of these pollutants at the plant shelters.

Rubber cracking was measured by exposing rubber strips under constant stress adjacent to each of the plant shelters. After exposure for 1 week, the rubber strips were examined microscopically to determine the average crack depth in millimeters. A linear relation is reported to exist between the extent of crack depth in rubber strips and the duration of exposure to a given concentration of O_3. According to Vega and Seymour,[13] if the exposure is 7 days, the average O_3 concentration can be approximated in pphm by multiplying the average crack depth in millimeters by 6.

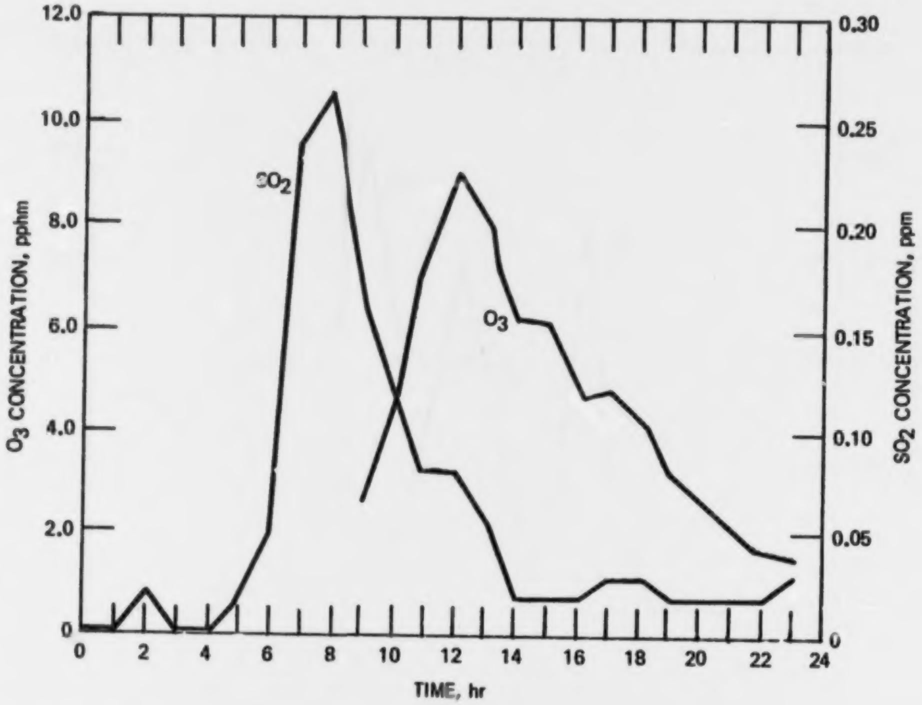

Figure 2-11. Hourly average concentration of SO_2 and O_3 for June 5, 1968, in Sarnia, Ontario, Canada.

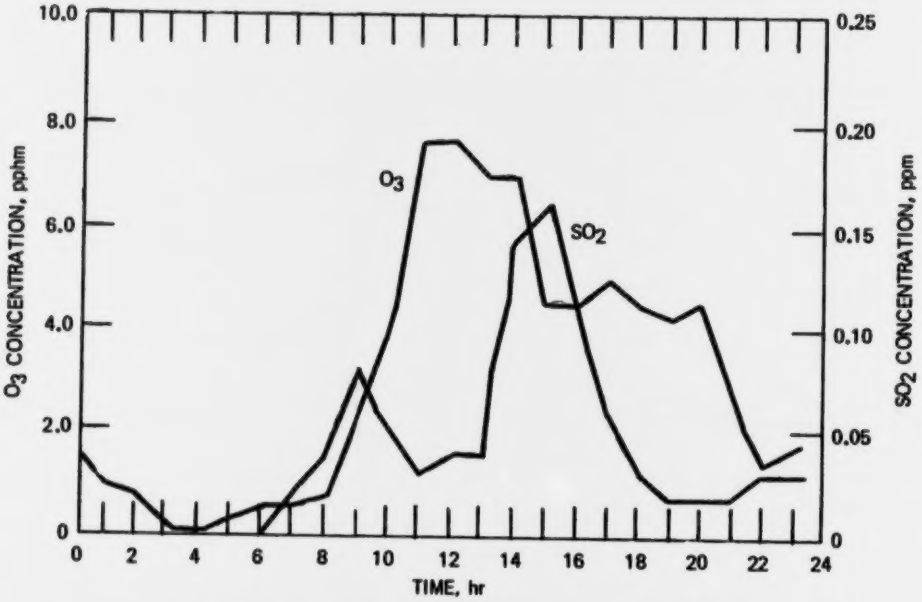

Figure 2-12. Hourly average concentration of SO_2 and O_3 for July 8, 1968, in Sarnia, Ontario, Canada.

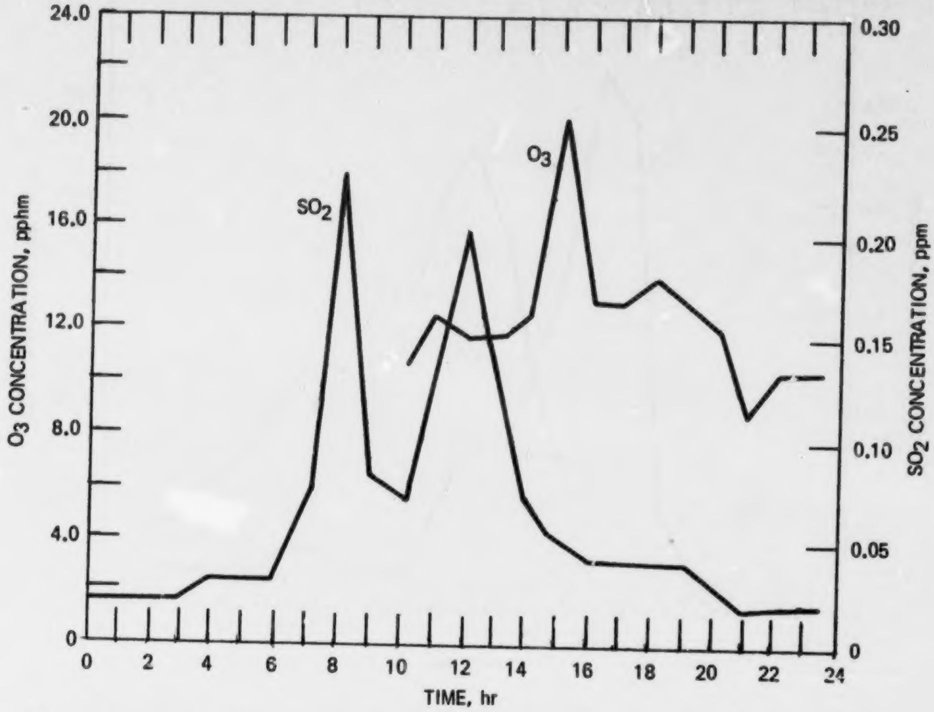

Figure 2-13. Hourly average concentration of SO_2 and O_3 for July 12, 1968, in Windsor, Ontario, Canada.

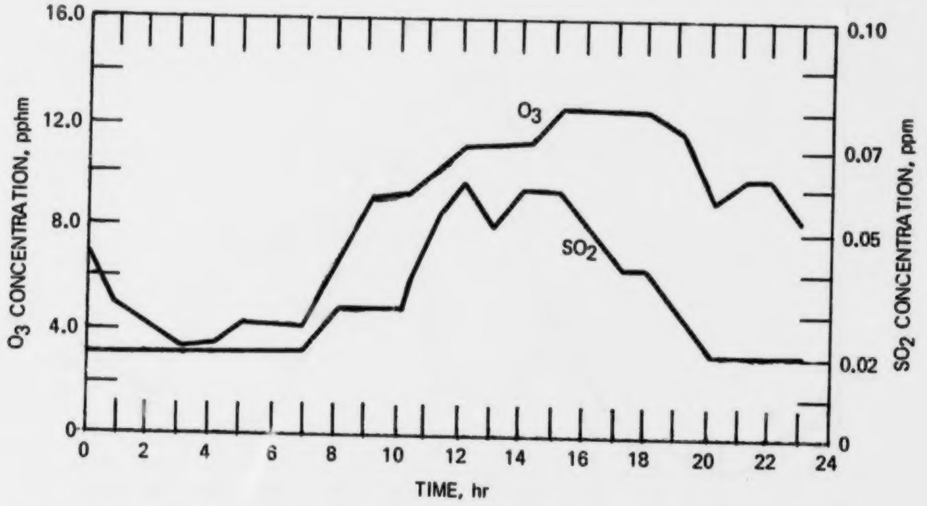

Figure 2-14. Hourly average concentration of SO_2 and O_3 for July 13, 1968, in Windsor, Ontario, Canada.

The average O_3 concentration for the entire 10 weeks, May 6 through July 17, 1968, was 1.0 pphm in Grosse Ile, 0.7 pphm in Belle Isle, Port Huron, and Sarnia, and 0.5 pphm in Windsor, as shown in Table 2-53.

Table 2-53. AVERAGE OZONE AND SULFUR DIOXIDE CONCENTRATIONS AND THE DAMAGE THAT DEVELOPED ON TOBACCO PLANTS FROM MAY 6 THROUGH JULY 17, 1968

	SO_2, pphm			
Stations	Candles	Plate	O_3, pphm	Injury, %
Grosse Ile	1.4	1.2	1.0	35
Belle Isle	2.1	1.9	0.7	40
Windsor	2.4	1.7	0.5	35
Sarnia	2.6	3.1	0.7	50
Port Huron	3.6	3.3	0.7	30

Sulfation, an indication of the long-term average SO_2 concentration, was measured by lead peroxide plates exposed in an effects shelter adjacent to each plant shelter. After exposure for approximately 5 weeks, the candles and plates were analyzed for total sulfate and the sulfation rate was calculated. Sulfation was highest in Port Huron, followed by Sarnia, Windsor, Belle Isle, and Grosse Ile, respectively (Table 2-53).

2.11.1.2.2 Nonspecific damage. In addition to tissue destruction, all plant species showed growth suppression. Comparable plants grown in the control station with activated carbon filters had longer leaves, a wider stem, a darker green color, and generally more vigorous growth and appearance. Table 2-54 lists the percentage by which exposed specimens were smaller than the control specimens of the same age. A value of 20 percent means that the growth of plants in an exposure chamber was estimated by visual comparison to be 20 percent less than that in the Grosse Ile control shelter. Table 2-55 lists measurements made of the root system of tobacco plants exposed for 10 weeks at the five stations. The root systems of the controls weighed more and the diameters of the stems of the controls were larger than those of the exposed plants. The tobacco plant grown in the Sarnia station had the smallest root system; its weight was approximately 46 percent of that of control plants and the stem diameter was two-thirds the size of control plant stems.

2.11.1.2.3 Fluorides. Fluoride is an accumulative toxicant, so that the development of plant injury is usually associated with the buildup of fluoride in the leaf over a relatively long period. This is in contrast to the action of most phytotoxicants, which normally cause injury within a short period of exposure. Hydrogen fluoride is toxic to some plants at concentrations as low as 0.1 ppb for 5 weeks.[14] All fluorides, particulate as well as gaseous, can accumulate either outside or inside the leaf and can cause injury to the leaf. Low concentrations also cause reductions in growth and food formation.

To find whether fluoride injured vegetation in the study areas snow princes, which are gladioli sensitive to fluoride, were planted in vermiculite at the five

Table 2-54. PERCENTAGE GROWTH SUPPRESSION OF SELECTIVE VEGETATION[a]

Plant	Grosse Ile	Windsor	Belle Isle	Port Huron	Sarnia	Control
Tobacco	35	35	40	30	50	0
Pinto bean	10	15	20	15	25	0
Petunia	20	30	35	20	60	0
Begonia	20	30	50	25	70	0
Geranium	15	30	45	20	50	0

[a] Estimated by visual comparison.

Table 2-55. COMPARISON OF EXPOSED AND CONTROL TOBACCO PLANTS GROWN BETWEEN MAY 6 AND JULY 17, 1968

	Grosse Ile	Windsor	Belle Isle	Port Huron	Sarnia	Control
Leaf area damaged, %	35	35	40	40	50	0
Diameter of stem, in.	1.75	1.60	1.50	1.50	1.20	1.80
Stem cross section area, in.^{2}	2.40	2.00	1.77	1.77	1.13	2.54
Cross section area, % less than control	6	21	30	30	56	0
Root system weight, g	650	800	750	775	430	925
Root system weight, % less than control	30	14	19	16	54	0

station sites. Tip and margin burns started to develop about 5 weeks after the gladioli were planted at the shelter sites. Leaf samples from gladioli grown at the sites were analyzed for fluoride content. The results of the analyses of leaf tissue are shown in Table 2-56.

2.11.2 Summary

Ozone and PAN caused damage to the selective vegetation. Ozone caused fleck, stipple, and bleaching on tobacco, pinto bean, and petunia plants. PAN damaged pinto bean plants. Ozone damaged plant varieties exposed at all five locations, whereas PAN only injured the plants exposed at Belle Isle and Sarnia. The effect associated with a given amount of O_3 in ambient air on Tobacco W3 was more severe in exposed plants than in laboratory plants exposed to the same concentration of O_3 because ambient air is contaminated with SO_2, which interacts with and enhances the effect of O_3 on vegetation.

Tobacco W3 was injured more severely in Sarnia than in other locations because of the higher concentrations of O_3 and SO_2 that occurred simultaneously there on several days during the course of the study. In Port Huron, the damage to plant varieties was not as severe as in Sarnia. Because emissions are carried by the wind from the power plants and oil refineries across St. Clair River, the SO_2 level in Port Huron appeared to be dependent upon wind direction. Synergistic

Table 2-56. FLUORIDE ACCUMULATION IN LEAF TISSUE OF GLADIOLI GROWING IN THE PLANT SHELTERS BETWEEN MAY 6 AND JULY 17, 1968

Station	Tip injury, in.	Distance from leaf tip, in.	F, μg/g
Grosse Ile	3 - 4	0 - 2	50 ± 25[a]
		2 - 4	25 ± 25
Windsor	2 - 3	0 - 2	30 ± 25
		2 - 4	30 ± 25
Belle Isle	3 - 4	0 - 2	45 ± 25
		2 - 4	25 ± 25
Port Huron	4 - 5	0 - 2	55 ± 25
		2 - 4	35 ± 25
Sarnia	2 - 3	0 - 2	25 ± 25
		2 - 4	25 ± 25

[a] The range (± figure) of the concentration is equivalent to the amount of the blank determination. When plants contain more than a few ppm F, atmospheric contamination is indicated.[15,16]

action also caused damage to tobacco exposed at Belle Isle because of high levels of SO_2 and O_3.

Limited fluoride accumulation was found in the leaves of gladioli grown in the study areas. Fluoride accumulation was higher in plants grown in Port Huron, Grosse Ile, Belle Isle, Windsor, and Sarnia, respectively.

Growth was suppressed in Tobacco W3, pinto bean, petunia, and geranium when the plants were grown for 10 weeks in ambient air in the study area. These plants were compared to similar plants grown in ambient air that was passed through activated carbon filters. Leaves of plants grown in carbon filtered air were longer, more vigorous, and darker green. The root systems of plants grown in carbon filtered air also were larger and more vigorous and the stem diameter was larger than those grown in unfiltered air. Finally, it may be said that the atmosphere to which plant varieties in the study areas were exposed contained a complex mixture of gases such as oxidants, PAN, SO_2, NO_2, fluoride, and others. Continuous exposure to a combination of pollutants in low concentrations may sensitize a plant or reduce its resistance to single or combined pollutants. Thus, short periods of pre-exposure of plants to a combination of gases in low concentrations may cause an increase in the damage that a pollutant can inflict.

2.12 VISIBILITY

Appropriate data were limited for assessing the effect on visibility of smoke traversing the boundary. The available data were analyzed, however, to estimate the extent of this effect. Data used in the analysis were from City and Metropolitan Airports in Detroit. Accordingly, the conclusions drawn from the data applied only to the Detroit River vicinity. Comparable data were not available for a similar analysis of the St. Clair River vicinity.

Hourly surface observation data for each of the two stations were analyzed for the study period, December 1967 through November 1968. The analytical method used was that of constructing a wind rose for only those hours when visibility was a given distance or less and the obstructing phenomenon was recorded as smoke or a combination of smoke and haze. Visibility, or visual range, is determined by a trained observer and is the farthest prevailing horizontal distance at which selected objects or markers can be seen. So that the roses would primarily show the effect of pollutants and not moisture, only those cases without precipitation or fog and with a relative humidity of 70 percent or less were considered. Hence, the roses indicated the area of origin of the air pollutants that reduced visibility at the two locations.

The selection of a visibility range below which any further reduction becomes objectionable to the public or to commercial elements is difficult. For this analysis, therefore, a visibility range was selected somewhat arbitrarily, although the selection was guided by restraints on the data and by the availability of literature pertaining to some of the major effects of visibility. A primary consideration was that in the official observations taken at the two airports, the obstructing phenomenon reducing the visibility was not recorded unless the visibility was reduced to 6 miles or less. Relative to effects of visibility, the Air Quality Criteria for Particulate Matter,[17] published by the U. S. Department of Health, Education, and Welfare, states: "In addition to aesthetic degradation of the environment, reduced visibility has many consequences for the safe operations of aircraft and motor vehicles. Federal (U. S.) air regulations prescribe limitations on aircraft operating under conditions of reduced visibility; they become increasingly severe as the visibility decreases from 5 miles to 3 miles to one mile." Based on the above considerations a smoke rose was constructed for each station for the cases in which visibility was reduced to less than 5 miles. The roses are shown in Figure 2-15.

The three most prominent legs on the roses, south through southwest for Metropolitan Airport and east through southeast for City Airport, indicated that the primary source area of the affecting smoke (or smoke and haze) was centered along the lower Detroit River vicinity. The conditions represented by the roses occurred 109 times at Metropolitan Airport and 416 times at City Airport. The relative infrequency of easterly winds, which advect smoke toward Metropolitan Airport, probably limited the occurrence of such conditions at that location.

From the analysis of conditions at the two major Detroit airports, some inferences can logically be made with regard to transboundary pollution. First, the indication that south to southeast winds affect visibility most at City Airport, and that a major proportion of the affecting pollutants have their origin in the lower Detroit River vicinity, lead to the conclusion that a portion of the pollutants from the downriver area were transported across the boundary. Pollutants from the U. S. side, where most of the pollution sources are situated, would have tended to cross into Canada and then back into the United States on their travel toward City Airport. Those pollutants emanating from the few sources in Canada that would have added to the overall pollutant load would have simply crossed the boundary into the United States to reach City Airport. Second, it would be reasonable to assume that if the two major Detroit airports have significant visibility effects due to air pollution, then the Windsor Airport or any other location in the vicinity of Windsor would be similarly affected. Since emissions are greater on the U.S. side, the reduction of visibility in Windsor would probably result primarily from the transboundary movement of pollutants. Finally, since westerly winds occur more frequently than easterly winds, visibility reductions caused by air contaminants are likely to occur more often on the Canadian than on the United States side.

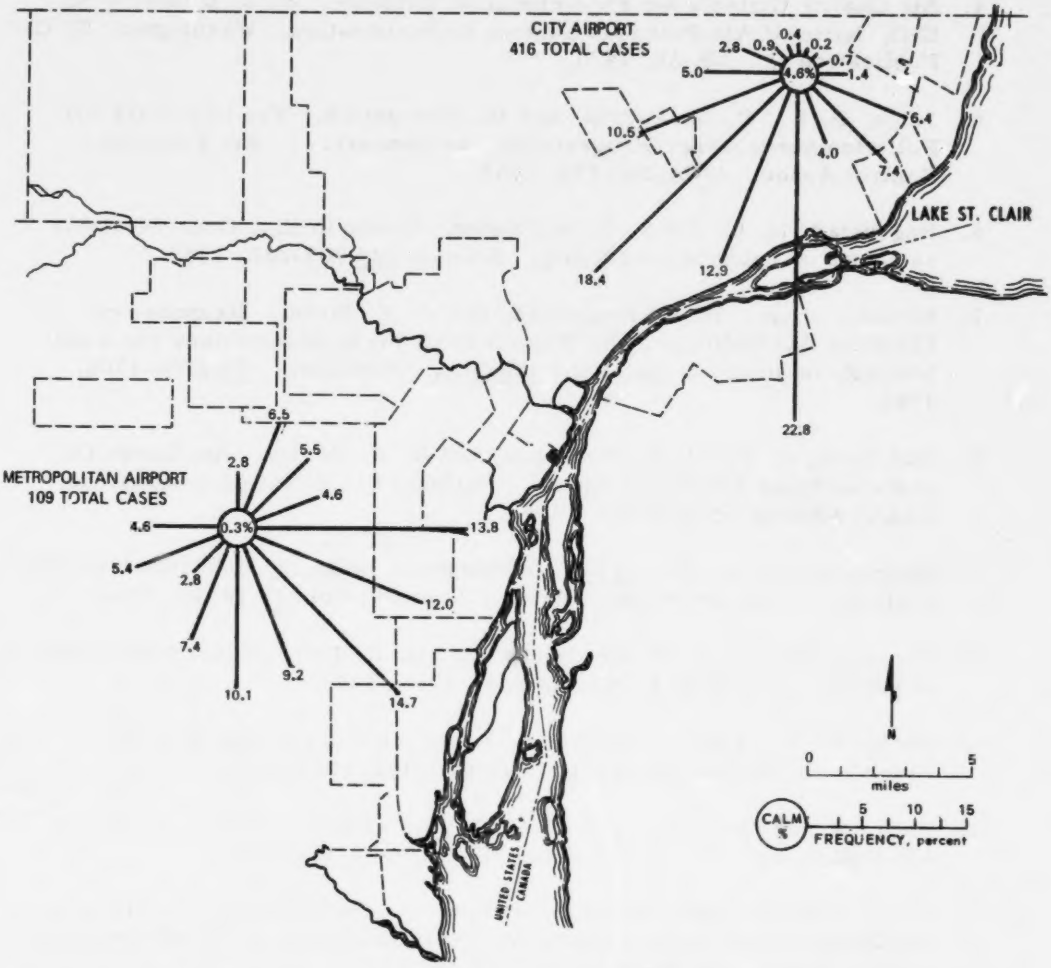
CITY AIRPORT
416 TOTAL CASES
4.6%
0.4
0.2
0.9
2.8
0.7
1.4
5.0
10.5
6.4
7.4
4.0
18.4
12.9
22.8
LAKE ST. CLAIR
METROPOLITAN AIRPORT
109 TOTAL CASES
0.3%
6.5
5.5
2.8
4.6
4.6
13.8
5.4
2.8
12.0
7.4
9.2
10.1
14.7
UNITED STATES
CANADA
N
0
5
miles
CALM %
5
10
15
FREQUENCY, percent

Figure 2-15. Visibility roses showing percent frequency of wind directions with occurrence of smoke and haze (relative humidity ≦ 70 %) restricting visibility to <5 miles at indicated airports. December 1967 through November 1968.

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3. EMISSIONS INVENTORY

An inventory of pollutant emissions from sources in the Port Huron - Sarnia, Detroit - Windsor area was compiled from data for the year 1967, for the counties of Essex, Kent, and Lambton in Ontario, and Wayne, Oakland, Macomb, and St. Clair in Michigan. The county boundaries were considered to extend to the international border where necessary to include emissions from ships. The types of pollutants reported were particulates, sulfur oxides (SO_x - primarily SO_2), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO).

The particulates emitted included both organic and inorganic matter from fuel combustion, charred cellulose from refuse combustion, oxidized gasoline additives (mainly lead compounds) from motor vehicles, mineral dust from asphalt-batching plants and cement plants, and metallurgical fumes and organic and inorganic dusts from industrial processes.

Sulfur oxides were found to include SO_2, which is primarily a product of combustion of sulfur-bearing fuels such as coal and fuel oils; SO_3, from industrial processes; sulfuric acid mist, from the acid production; and SO_x, from crude oil refining and coke production.

Nitrogen oxides are produced during the combustion of all fuels, from both mobile and stationary sources.

Hydrocarbons and CO are usually products of inefficient fuel combustion; however, they also emanate from the petrochemical industry. Even though large quantities of fuel are consumed in power plants, the high boiler temperatures result in low HC and CO emissions. Combustion of gasoline in the internal combustion engine and open burning of refuse result in high HC and CO emissions.

3.1 PROCEDURE

The year 1967 was used as a base for determining emissions since that was the last complete year for which data were available. The quantity of each fuel sold by retail dealers and the quantity sold to industries were determined and used in calculating emissions from fuel combustion. Data on traffic volumes, gasoline consumption, diesel fuel consumption by trains and trucks, and fuel consumption by ships and aircraft were gathered and used in calculating emissions from mobile sources. The quantity of refuse generated in the area and methods of disposal were determined; then the data were used to calculate emissions from burning refuse. Data on industrial processes were collected by questionnaires sent to the larger companies. Calculations of process emissions were made with the help of these data; also, observations were made of some of the processes.

Any individual site that emitted 100 tons or more of any single pollutant per year was considered as a point source. There were 178 such point sources.

Activities emitting less than 100 tons of a pollutant per year were grouped on an area basis and were collectively considered as an area source. Areas were graduated in size - 1, 3, or 5 kilometers on a side - inversely, according to the industrial activity. Nearly 2,000 area sources were designated in the seven U.S. and Canadian counties of the study region. These areas are shown in Figure 3-1.

3.2 RESULTS OF EMISSIONS SURVEY

The contaminants discharged to the atmosphere in 1967 are listed in Table 3-1 by types, source categories, and counties for the Detroit - Windsor and Port Huron - Sarnia areas. The relative importance of the contribution of sources in each country in the two areas, Port Huron - Sarnia and Detroit - Windsor, is shown in Table 3-2.

3.2.1 Port Huron - Sarnia Area

This area consists of St. Clair County on the Michigan side and Lambton County on the Ontario side of the international border. Table 3-1 presents statistics on emissions of each type of pollutant by source categories in each of the two counties.

The 51,000 tons of particulates emitted in 1967 were principally from industrial fuel combustion in Lambton County and power plants in St. Clair County, 44 and 37 percent, respectively. The next largest sources were industrial process losses in Lambton County, 6 percent, and industrial process losses, 3 percent, in St. Clair County. The remaining 7 percent was well distributed in the other source categories.

Of the 373,000 tons of SO_x emissions, the main contribution was from fuel combustion by the three U. S. steam-electric power plants, 74 percent; followed by industrial fuel combustion, 22 percent; and industrial process losses, 5 percent, in Lambton County.

The 71,000 tons of NO_x emissions was from U. S. power plants, 62 percent; industrial fuel combustion in Canada, 27 percent; U. S. industrial fuel combustion, 2 percent; and less in other categories.

The HC emissions, 67,000 tons, were from industrial process losses and gasoline-handling losses in Canada, 56 and 15 percent, respectively; followed by gasoline-fueled vehicles and open burning of refuse in the U. S., 9 and 6 percent, respectively; and by gasoline-fueled vehicles in Canada, 5 percent. The remaining 9 percent was emitted by all other source categories.

The 209,000 tons of CO emissions was from the following source categories; industrial process losses in Canada, 74 percent; gasoline combustion in vehicles in the U. S. and Canada, 15 and 8 percent, respectively; and 3 percent distributed over the remaining categories.

3.2.2 Detroit - Windsor Area

Of the 258,000 tons of particulate emissions in the Detroit - Windsor area, 61 percent came from the U. S.: industrial process losses, 23 percent; steam-electric power plants, 22 percent; and industrial fuel combustion, 16 percent.

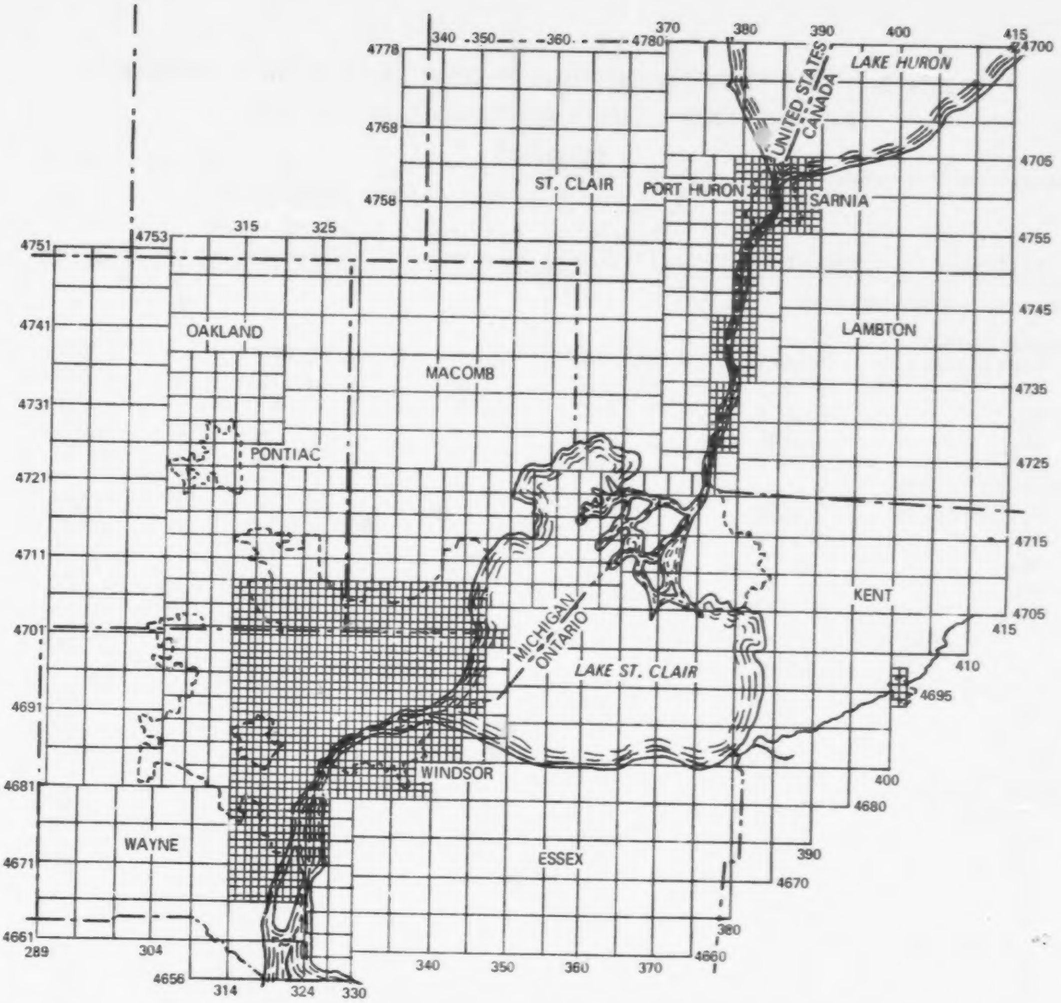
LAKE HURON
UNITED STATES
CANADA
ST. CLAIR
PORT HURON
SARNIA
LAMBTON
OAKLAND
MACOMB
PONTIAC
KENT
MICHIGAN
ONTARIO
LAKE ST. CLAIR
WINDSOR
WAYNE
ESSEX
340
350
360
370
380
390
400
415
4778
4780
4700
4768
4705
4758
4755
4751
4753
315
325
4741
4745
4731
4735
4721
4725
4711
4715
4701
4705
415
410
4695
4691
4681
400
4680
4671
390
4670
4661
289
304
4656
314
324
330
340
350
360
370
380
4660

Figure 3-1. Port Huron—Sarnia and Detroit—Windsor source areas for emission inventories.

Almost 94 percent of the emissions from these three types of sources occurred in Wayne County. Other source categories each contributed less than 7 percent of the total particulate emissions in the area.

The 551,000 tons of SO_x emissions in the Detroit - Windsor area came from power plants in Wayne County, 55 percent; U. S. industrial fuel combustion, 21 percent, of which almost four-fifths was in Wayne County; and U. S. commercial and government fuel combustion, 7 percent. Other source categories each contributed less than 5 percent of the total.

Of the 271,000 tons of NO_x emission in the Detroit - Windsor area, the major sources were: gasoline combustion in U. S. mobile sources, 28 percent; power plants in Wayne County, 26 percent; U. S. industrial fuel combustion, 20 percent; and U. S. commercial and government fuel combustion, 7 percent.

Table 3-1. AIR POLLUTION EMISSIONS BY COUNTIES IN DETROIT - WINDSOR AND PORT HURON - SARNIA AREAS, BASED ON 1967 DATA

(tons/yr)

Pollutant	Stationary sources of fuel combustion				
	Industrial	Power utilities	Heating plants	Commercial and government	Residential
Detroit - Windsor area					
Wayne County					
Particulates	34,418	56,209	4,999	10,042	7,001
SO_x	89,498	305,060	9,100	29,170	11,761
NO_x	45,558	69,542	4,223	12,559	7,248
HC	1,187	722	51	3,317	3,119
CO	3,478	4,403	133	15,690	14,736
Oakland County					
Particulates	2,438	---	---	2,000	1,236
SO_x	8,172	---	---	5,482	1,956
NO_x	3,407	---	---	3,517	2,213
HC	113	---	---	596	462
CO	317	---	---	2,764	1,597
Macomb County					
Particulates	4,563	---	---	4,342	720
SO_x	16,275	---	---	3,840	1,116
NO_x	5,681	---	---	2,055	1,423
HC	222	---	---	339	256
CO	639	---	---	1,530	817
Essex County					
Particulates	12,466	695	---	354	122
SO_x	9,491	15,840	---	1,917	476
NO_x	5,369	3,970	---	780	517
HC	228	40	---	106	28
CO	632	99	---	467	93
Kent County					
Particulates	116	---	---	32	20
SO_x	978	---	---	192	59
NO_x	595	---	---	103	89
HC	16	---	---	7	4
CO	43	---	---	29	12
Port Huron - Sarnia area					
St. Clair County					
Particulates	1,495	18,975	---	233	506
SO_x	3,481	266,000	---	656	396
NO_x	1,461	43,863	---	399	391
HC	84	439	---	71	235
CO	272	1,095	---	325	1,061
Lambton County					
Particulates	22,209	---	---	120	50
SO_x	80,368	---	---	618	214
NO_x	18,907	---	---	303	188
HC	571	---	---	34	14
CO	1,376	---	---	142	46

Table 3-1 (continued). AIR POLLUTION EMISSIONS BY COUNTIES IN DETROIT - WINDSOR AND PORT HURON - SARNIA AREAS, BASED ON 1967 DATA
(tons/yr)

	Mobile sources of fuel combustion				
	Vehicles				
Pollutant	Gasoline	Diesel	Trains	Ships	Aircraft
Detroit - Windsor area					
Wayne County					
Particulates	6,884	3,129	825	1,316	216
SO_x	3,610	1,138	300	2,948	0
NO_x	39,175	6,314	1,665	2,746	675
HC	155,592	3,868	1,020	158	2,191
CO	964,207	1,707	450	149	10,103
Oakland County					
Particulates	2,319	271	---	---	---
SO_x	1,739	99	---	---	---
NO_x	21,835	547	---	---	---
HC	49,977	335	---	---	---
CO	444,429	148	---	---	---
Macomb County					
Particulates	1,476	120	---	1,418	2
SO_x	1,109	44	---	2,161	0
NO_x	13,895	242	---	3,444	17
HC	31,804	148	---	950	64
CO	282,820	65	---	424	302
Essex County					
Particulates	305	524	177	2,455	9
SO_x	228	234	79	4,498	---
NO_x	3,241	1,056	357	1,613	40
HC	8,110	652	219	211	146
CO	55,014	289	96	250	719
Kent County					
Particulates	79	135	87	---	---
SO_x	57	60	39	---	---
NO_x	841	273	175	---	---
HC	2,016	166	107	---	---
CO	12,933	93	47	---	---
Port Huron - Sarnia area					
St. Clair County					
Particulates	210	140	---	498	---
SO_x	105	51	---	2,120	---
NO_x	1,287	282	---	601	---
HC	6,310	173	---	109	---
CO	30,422	76	---	164	---
Lambton County					
Particulates	106	187	46	298	---
SO_x	81	84	20	897	---
NO_x	1,178	378	93	297	5
HC	3,024	232	57	64	20
CO	15,781	102	25	53	106

Table 3-1 (continued). AIR POLLUTION EMISSIONS BY COUNTIES IN DETROIT - WINDSOR AND PORT HURON - SARNIA AREAS, BASED ON 1967 DATA

(tons/yr)

Pollutants	Refuse combustion		
	Municipal incinerators	Private incinerators	Open burning
Detroit - Windsor area			
Wayne County			
Particulates	2,412	4,801	9,284
SO_x	700	359	0
NO_x	700	599	278
HC	105	145	67,309
CO	351	5,985	27,852
Oakland County			
Particulates	493	1,602	4,162
SO_x	145	120	0
NO_x	145	200	125
HC	22	48	30,173
CO	73	2,002	12,488
Macomb County			
Particulates	---	708	3,134
SO_x	---	53	0
NO_x	---	88	94
HC	---	21	22,723
CO	---	885	9,402
Essex County			
Particulates	---	44	189
SO_x	---	4	---
NO_x	---	6	130
HC	---	1	354
CO	---	62	1,003
Kent County			
Particulates	60	1	61
SO_x	9	---	---
NO_x	9	---	42
HC	1	---	114
CO	4	6	322
Port Huron - Sarnia area			
St. Clair County			
Particulates	---	44	515
SO_x	---	3	0
NO_x	---	6	16
HC	---	1	3,732
CO	---	55	1,545
Lambton County			
Particulates	---	36	367
SO_x	---	4	---
NO_x	---	4	252
HC	---	---	688
CO	---	13	1,950

Table 3-1 (continued). AIR POLLUTION EMISSIONS BY COUNTIES IN DETROIT - WINDSOR AND PORT HURON - SARNIA AREAS, BASED ON 1967 DATA

(tons/yr)

Pollutants	Process losses			Total all sources
	Industrial	Gasoline handling and storage	Solvent losses	
Detroit - Windsor area				
Wayne County				
Particulates	55,924	---	---	197,460
SO_x	20,003	---	---	473,647
NO_x	1,637	---	---	192,919
HC	30,252	15,787	16,331	301,154
CO	43,738	---	---	1,092,982
Oakland County				
Particulates	3,053	---	---	17,574
SO_x	664	---	---	18,377
NO_x	111	---	---	32,100
HC	2,495	5,294	10,075	99,590
CO	6,696	---	---	470,514
Macomb County				
Particulates	26	---	---	16,509
SO_x	0	---	---	24,598
NO_x	0	---	---	26,939
HC	957	3,369	6,682	67,715
CO	20	---	---	296,905
Essex County				
Particulates	8,419	---	---	25,759
SO_x	---	---	---	32,767
NO_x	---	---	---	17,079
HC	3,719	2,780	259	16,853
CO	---	---	---	58,724
Kent County				
Particulates	355	---	---	946
SO_x	---	---	---	1,394
NO_x	---	---	---	2,127
HC	655	362	6	3,464
CO	28	---	---	13,517
Port Huron - Sarnia area				
St. Clair County				
Particulates	1,600	---	---	24,216
SO_x	99	---	---	273,411
NO_x	948	---	---	49,254
HC	1,349	674	931	14,108
CO	0	---	---	35,015
Lambton County				
Particulates	3,232	---	---	26,216
SO_x	17,356	---	---	99,642
NO_x	346	---	---	21,951
HC	37,796	10,323	---	52,823
CO	154,393	---	---	173,987

Table 3-2. RELATIVE ANNUAL EMISSIONS FROM UNITED STATES AND CANADIAN SOURCES IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREAS, 1967

Pollutant	Emissions, Port Huron - Sarnia			Emissions, Detroit - Windsor		
	Total, 10^3 tons	United States, %	Canadian, %	Total, 10^3 tons	United States, %	Canadian, %
Particulates	51	48	52	258	90	10
SO_x	373	73	27	551	94	6
NO_x	71	69	31	271	93	7
HC	67	21	79	489	96	4
CO	209	17	83	1,933	96	4

The HC emissions were mostly from gasoline combustion in U. S. vehicles, 49 percent, and open burning of refuse in the U. S., 25 percent. Each other source category contributed less than 7 percent.

The CO emissions were almost entirely from gasoline combustion in vehicles, 87.5 percent in the U. S. and 3.5 percent in Canada. The other 9 percent of CO emissions was distributed over the remaining source categories.

3.3 FUEL COMBUSTION AT STATIONARY SOURCES (Total Study Area)

Coal, fuel oil, and natural gas were considered to be the only significant fuel types used in the study area for space, water, and process heating. Fuel oil and coal are significant sources of particulates and SO_x. They emit more pollutants to the atmosphere than does natural gas; the principal contaminants resulting from the combustion of natural gas are NO_x.

Fuel combustion in residential dwelling units is a source that affects the level of pollution in a wide area. Residential fuel combustion was the source of only 3 percent of the area's particulate emissions, 2 percent of the SO_x emissions, 4 percent of the NO_x emissions, less than 1 percent of the HC emissions, and 1 percent of the total CO emissions.

Coal is used in a large number of dwelling units on the U. S. side of this border area, ranging from 20 percent of the homes in rural areas and the older dwelling units in the heart of Detroit to less than 4 percent of the homes in suburban areas. It was assumed that only 1 percent of the dwelling units on the Canadian side used coal as a fuel. Fuel oil is used in nearly 40 percent of the U. S. homes and only 16 percent of the Canadian homes in the area. Natural gas is the fuel used in most of the remaining homes. Electricity is used exclusively in a very small percentage of the dwelling units.

Fuel consumed for space and water heating for all nonindustrial, nonresidential buildings is classified as commercial and governmental use. Commercial and governmental fuel combustion was the source of 6 percent of the area's particulate emissions, 5 percent of the SO_x emissions, 6 percent of the NO_x emissions, less than 1 percent of the HC emissions, and 1 percent of total CO emissions. Commercial and governmental establishments use a significant quantity of bituminous coal and residual and distillate fuel oils. These fuels accounted for most of the particulate and SO_x emissions from this source category.

Six heating plants in Detroit supply steam heat to commercial and governmental facilities and appartment buildings. These are all coal-fired and discharged nearly 2 percent of the area's total particulate emissions and approximately 1 percent of the SO_x and NO_x emissions.

Industrial fuel combustion for space heating, process heat, and steam and power generation released approximately 25 percent of the particulate emissions, 21 percent of the SO_x emissions, and 24 percent of the NO_x emissions. Because the larger industrial boilers usually operate at high combustion temperatures, less than 0.5 percent of the area's HC and CO emissions emanated from industrial fuel combustion processes.

In the Canadian area, industrial fuel combustion was the source of 65 percent of all particulate emissions, 68 percent of all SO_x emissions, and 60 percent of all NO_x emissions. The greatest portion of these emissions is the result of the use of large amounts of bituminous coal by industry. In the U. S. area, industrial fuel combustion constituted approximately 17 percent of the particulate emissions, 15 percent of the SO_x emissions, and 19 percent of the NO_x emissions.

There are 13 steam-electric power utilities in this area. Nine are located in Wayne County and one in Essex County, along the Detroit River. The other three power plants are in St. Clair County along the St. Clair River. Bituminous coal was used in all of these plants during 1967. There are plans to convert some of the boilers to oil and gas burners. Steam-electric power plants were the source of 25 percent of the particulates, 64 percent of the SO_x, 34 percent of the NO_x, and small amounts (less than 0.5 percent) of the HC and CO emissions for the study area.

The 12 power plants on the U.S. side discharged approximately 29 percent of the particulate emissions, 72 percent of the SO_x emissions, and 38 percent of the NO_x emissions from the U.S. area. In the Detroit - Windsor area, the nine U.S. power plants discharged 22 percent of the particulate emissions, 55 percent of the SO_x emissions, and 26 percent of the NO_x emissions. In the Port Huron - Sarnia area, the U.S. power plants emitted 30 percent of the particulate emissions, 74 percent of the SO_x emissions, and 62 percent of the NO_x emissions.

3.4 FUEL COMBUSTION IN MOBILE SOURCES

Included under the category of mobile sources are emissions from gasoline- and diesel-fueled motor vehicles; diesel railroad engines; ships on the St. Clair River, Detroit River, and Lake St. Clair; and emissions from aircraft. Altogether, mobile sources discharged approximately 8 percent of the particulate emissions, 2 percent of the SO_x emissions, 30 percent of the NO_x emissions, 48 percent of the HC emissions, and 85 percent of the CO emissions. Automobiles accounted for a major portion of NO_x, HC, and CO emissions, discharging 24 percent, 46 percent, and 84 percent of these pollutants, respectively.

In the U. S. area, automobiles were the source of 25 percent of the NO_x emissions, 51 percent of the HC emissions, and 91 percent of the CO emissions. In the Canadian portion, automobiles were the source of 13 percent of the NO_x emissions, 18 percent of the HC emissions, and 34 percent of the CO emissions.

3.5 REFUSE DISPOSAL

Nearly all refuse collected and disposed of under sponsorship of a municipal government is burned in an incinerator or deposited in a sanitary landfill.

The City of Detroit operates four large incinerators and two brush burners; several smaller communities also have organized incinerator authorities to solve their solid-waste disposal problem. Nearly all of these incinerators are controlled to some extent, but each emits over 100 tons of particulates per year.

Although open-burning dumps are unlawful in the State of Michigan, such burning did take place in 1967. Open-burning refuse is assumed to consist of household waste paper, waste paper from the offices of small business establishments located outside the city, and some industrial and agricultural wastes. The large proportion of paper, garden trimmings, and agriculture wastes included in the refuse resulted in HC emissions of 123,000 tons per year (or 145 pounds per ton of refuse burned) in the U. S. area. That was 26 percent of the total HC emissions in that area; open burning also discharged 7 percent of the particulate emissions.

Open burning is unlawful in the Province of Ontario; nevertheless, some municipal refuse is burned in dumps, but the total emissions are small. Open-burning emissions constituted only 1 percent of the NO_x emissions, 2 percent of the HC emissions, and 1 percent of the CO emissions for the area. Particulate emissions from the combustion of refuse constituted slightly more than 1 percent of the total particulate emissions. Most of this was from open burning.

The combustion of refuse was the source of 9 percent of the total particulate emissions, less than 1 percent of the SO_x emissions, 1 percent of the NO_x emissions, 23 percent of the HC emissions (all from open burning), and 3 percent of the CO emissions.

3.6 PROCESS AND SOLVENT LOSSES

In the U. S. area, gasoline handling and storage losses produced HC emissions of 25,100 tons per year or 5 percent of the total. In the Canadian area, a loss of 13,500 tons of HC, or 18 percent of the total, resulted from gasoline handling and storage losses.

The major portion of industrial process losses came from major point sources, listed in Table 3-3. Losses from smaller companies that reported on their processes are also included.

Industrial process losses constituted 24 percent of the particulate emissions in the area, 4 percent of the SO_x emissions, 1 percent of the NO_x emissions, 14 percent of the HC emissions, and 10 percent of the CO emissions.

Table 3-3. POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967

(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
														HC		
	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	Process	Solvent	CO
United States:																
Wayne County																
Chrysler Corp.																
1. Chemical Div., Trenton Plant	1	-	7	-	-	-	-	-	-	-	34	-	-	-	500	-
2. Trenton Engine Plant	116	1,688	311	15	47	12	71	18	4	3	3	-	-	-	225	-
3. Jefferson Assembly Plant	1,013	2,107	720	7	18	-	-	-	-	-	2	-	-	-	3,448	-
4. Mack Avenue Stamping Plant	636	439	262	[illegible]	36	-	-	-	-	-	55	-	-	-	-	-
5. Hamtramck Assembly Plant	1,925	2,090	1,100	[illegible]	28	-	-	-	-	-	3	-	-	-	4,795	-
6. Huber Foundry	8	-	96	-	-	-	-	-	-	-	85	184	-	-	-	-
7. Highland Park Machining	86	80	139	3	8	8	2	2	4	36	5	-	-	-	82	-
8. Detroit Forge Plant	7,084	587	1,030	10	26	-	-	-	-	-	4	-	-	-	126	-
9. Eldon Ave. Axle Plant	2,084	-	-	-	-	-	-	-	-	-	3	-	-	-	788	-
10. Lynch Rd. Engine Plant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,000	-
11. Mound Rd. Engine Plant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	143	-
12. Eight Mile Stamping Plant	750	587	300	3	.8	-	-	-	-	-	-	-	-	-	-	-
Ford Motor Co.																
13. Wayne Assembly Plant	530	1,010	266	13	40	-	-	-	-	-	-	-	-	-	-	-
14. Engine and Foundry Div.	-	-	-	-	-	-	-	-	-	-	3,281	-	-	-	-	-
15. Steel Div. Powerhouse	4,000	11,400	6,891	68	170	-	-	-	-	-	-	-	-	-	-	-
16. Steel Div.	-	-	-	-	-	-	-	-	-	-	3,275	3,100	-	-	-	-
17. Schaefer Rd. Dump	-	-	-	-	-	166	-	114	52	880	-	-	-	-	-	-
18. Dearborn Glass Plant	-	-	-	-	-	-	-	-	-	-	70	285	-	-	-	-
19. Dearborn Stamping Plant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	185	-
20. Elm St. Powerhouse	11	-	127	-	-	-	-	-	-	-	-	-	-	-	-	-
General Motors Corp.																
21. Fisher Body Div., Fleetwood Plant	99	309	199	10	30	-	-	-	-	-	12	-	-	-	3,000	-
22. Cadillac Motor Car Co.	45	2,460	693	32	97	-	-	-	-	-	-	-	-	-	458	-
23. Chevrolet Motor Div., Livonia Plant	217	1,786	501	25	75	-	-	-	-	-	48	-	-	-	-	-
24. Fisher Body Div., Detroit Central Plant	81	321	137	7	21	-	-	-	-	-	-	-	-	-	30	-
25. Fisher Body Div., Livonia Plant	49	168	98	5	15	-	-	-	-	-	-	-	-	-	30	-
26. Detroit Diesel Engine Div.	5	-	60	-	-	5	2	4	1	19	630	-	-	-	77	-
27. Chevrolet Motor Div., Detroit Forge Plant	2,273	4,391	1,650	82	246	-	-	-	-	-	-	-	-	-	-	-

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967

(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC		CO
														Process	Solvent	
28. American Motors	76	129	27	34	170	-	-	-	-	-	-	-	-	-	-	-
29. Kelsey Hayes Co.[a]	128	785	287	14	39	-	-	-	-	-	277	-	-	-	-	-
30. Budd Co.	11	-	132	-	-	-	-	-	-	-	23	-	-	-	303	-
31. Champion Spark Plug Co.	2	-	27	-	-	1	-	-	-	3	183	-	-	-	-	-
32. Lear-Siegler Co., Inc.	4	2	37	-	-	-	-	-	2	1	-	-	-	-	148	-
33. Dana Corp.	40	230	126	6	18	-	-	-	-	-	3	-	-	-	500	-
34. Great Lakes Steel Co.[a]	-	-	-	-	-	-	-	-	-	-	27,289	4,438	-	-	-	-
35. McLouth Steel Corp.	507	613	5,254	7	16	-	-	-	-	-	6,377	-	-	-	-	-
36. Valcan Mold and Iron Co.	1	-	14	-	-	-	-	-	-	-	101	-	-	-	-	-
37. Firestone Steel Products Co.	2	-	11	-	-	-	-	-	-	-	-	-	-	-	400	-
38. Huron Valley Steel Co.	10	26	47	1	1	-	-	-	-	-	609	-	-	-	-	8,750
39. Young Spring and Wire Corp.	3	19	9	-	-	-	-	-	-	2	-	-	-	-	458	-
40. Wolverine Aluminum Corp.	-	-	-	-	-	2	-	-	-	5	-	-	-	-	1,015	-
41. Unistrut Corp.	-	-	5	-	-	3	-	-	9	8	-	-	-	-	155	-
42. Whitehead and Kales[a]	4	10	18	-	-	-	-	-	-	-	-	-	-	-	788	-
43. Wolverine Tube Div., Calumet and Hecla, Inc.	5	24	15	-	-	-	-	-	-	-	-	-	-	-	131	-
44. Revere Copper and Brass Div.	3	9	23	-	-	1	-	-	-	5	170	-	-	-	-	-
45. Hoskins Manufacturing Co.	1	-	5	-	-	3	-	-	-	1	5	-	-	-	135	-
46. Brass Craft Manufacturing Co.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	288	-
47. Evans Products Co.	2	-	28	-	-	20	-	-	40	36	13	-	-	-	250	-
48. Bathey Manufacturing Co.	-	-	5	-	-	-	-	-	-	-	-	-	-	-	105	-
49. Huck Manufacturing Co.	1	-	6	-	-	-	-	-	-	-	-	-	-	-	118	-
50. Monsanto	4	-	52	-	-	-	-	-	-	-	300	-	-	-	-	-
51. Pennwalt Chemical Corp.	2	1	21	-	-	-	-	-	-	-	111	300	50	-	-	3
52. Wyandotte Chemical Corp., South Plant	7	-	89	-	-	7	-	-	13	13	1,529	132	-	-	-	22,380
53. Wyandotte Chemical Corp., North Plant	4	-	45	-	-	12	-	-	21	21	742	-	-	-	-	12,585
54. Detroit Chemical Corp.	-	-	-	-	-	-	-	-	-	-	-	1,750	-	-	-	-
Allied Chemical Corp.																
55. Industrial Chemicals Div.	-	-	-	-	-	-	-	-	-	-	85	2,700	-	-	-	-
56. Detroit Alkali Works	2,606	2,850	1,361	60	180	-	-	-	-	-	700	-	-	-	-	-
57. Semet Solvay Div.	255	684	174	-	-	-	-	-	-	-	+563[b]	-	-	-	-	-
58. DuPont	-	-	-	-	-	-	-	-	-	-	-	2,200	-	-	-	-
59. Park-Davis and Co.	159	468	250	9	28	3	-	1	-	-	4	-	-	-	-	-
60. Scott Paper Co.	1,487	1,744	1,080	54	162	-	-	-	-	-	-	600	-	-	-	-

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967

(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	HC		CO
														Process	Solvent	
61. Detroit Gravure Corp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	844	-
62. U. S. Rubber Tire Co.	1,466	1,976	1,300	65	195	-	-	-	-	-	-	-	-	-	-	-
63. Acme Quality Paint	-	-	13	-	-	-	-	-	-	-	-	-	-	-	616	-
64. Fred Sanders Co.	155	91	22	24	119	1	-	1	-	3	-	-	-	-	-	-
65. American Can Co.	-	-	2	-	-	-	-	-	-	-	2	-	-	-	391	-
66. Export Processing Co.	7	47	22	1	1	-	-	-	-	-	-	-	-	-	205	-
67. Mobile Oil Corp.	57	2,283	675	-	-	-	-	-	-	-	75	216	-	2,189	-	-
68. Marathon Oil Co.	87	3,300	-	-	-	-	-	-	-	-	1,800	3,900	-	2,955	-	-
69. Sun Oil Co.	2	6	11	-	-	-	-	-	-	-	-	-	-	920	-	-
70. Marblehead Lime Co.	-	-	92	-	-	-	-	-	-	-	105	-	-	-	-	-
71. U. S. Gypsum Co.	-	-	-	-	-	-	-	-	-	-	190	-	-	-	-	-
72. Peerless Div., American Cement Corp.	-	-	-	-	-	-	-	-	-	-	1,280	55	530	-	-	-
73. Peerless	11	220	42	2	6	-	-	-	-	-	990	99	945	-	-	-
Edward Levy Company																
74. Levy Slag[b]	-	-	-	-	-	-	-	-	-	-	1,000	-	-	-	-	-
75. Levy Slag[b]	-	-	-	-	-	-	-	-	-	-	1,000	-	-	-	-	-
76. Slag and Asphalt Batching[b]	-	-	-	-	-	-	-	-	-	-	687	-	-	-	-	-
77. Asphalt Batching	-	-	-	-	-	-	-	-	-	-	125	-	-	-	-	-
78. Slag and Asphalt Batching[b]	-	-	-	-	-	-	-	-	-	-	1,787	-	-	-	-	-
79. Detroit Lime Co.	672	205	257	-	-	-	-	-	-	-	200	-	-	-	-	-
80. Wayne County General Hospital	404	572	350	18	54	-	-	-	-	-	-	-	-	-	-	-
81. University of Detroit Heating	96	257	50	2	7	-	-	-	-	-	-	-	-	-	-	-
82. Arrow Wrecking Co. Incinerator	-	-	-	-	-	364	3	4	26	1,105	-	-	-	-	-	-
83. City of Trenton Incinerator	-	-	-	-	-	27	8	8	1	4	-	-	-	-	-	-
84. City of Ecorse Incinerator	-	-	-	-	-	133	16	16	2	8	-	-	-	-	-	-
85. Central Wayne County Incinerator	-	-	-	-	-	442	130	130	20	65	-	-	-	-	-	-
86. City of Detroit, 24th St. Incinerator	-	-	-	-	-	374	110	110	16	55	-	-	-	-	-	-
87. City of Detroit, Central Incinerator	-	-	-	-	-	400	118	118	18	59	-	-	-	-	-	-
88. City of Detroit, North West Incinerator	-	-	-	-	-	447	131	131	80	66	-	-	-	-	-	-
89. City of Detroit, St. Jean St. Incinerator	-	-	-	-	-	327	96	96	14	48	-	-	-	-	-	-

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967
(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC Process	HC Solvent	CO
90. City of Hamtramck Incinerator	-	-	-	-	-	177	52	52	8	26	-	-	-	-	-	-
Detroit Edison Company																
91. Trenton Channel Power Plant[a]	3,895	45,900	13,475	135	337	-	-	-	-	-	-	-	-	-	-	-
92. Pennsalt Power Plant	3,300	3,800	1,700	17	43	-	-	-	-	-	-	-	-	-	-	-
93. Wyandotte South Power Plant[a]	5,770	5,100	2,000	20	50	-	-	-	-	-	-	-	-	-	-	-
94. Wyandotte North Power Plant[a]	14,510	10,800	4,130	41	103	-	-	-	-	-	-	-	-	-	-	-
95. River Rouge Power Plant[a]	7,340	141,500	21,880	219	546	-	-	-	-	-	-	-	-	-	-	-
96. Delray Power Plant[a]	3,470	21,900	9,200	92	230	-	-	-	-	-	-	-	-	-	-	-
97. Conners Creek Power Plant[a]	14,800	71,100	16,390	164	410	-	-	-	-	-	-	-	-	-	-	-
98. Congress Street Heating Plant[a]	566	600	310	3	8	-	-	-	-	-	-	-	-	-	-	-
99. Beacon Street Heating Plant[a]	2,590	5,200	2,880	29	72	-	-	-	-	-	-	-	-	-	-	-
100. Willis Avenue Heating Plant[a]	1,183	1,450	762	8	19	-	-	-	-	-	-	-	-	-	-	-
101. Boulevard Heating Plant[a]	75	100	55	1	1	-	-	-	-	-	-	-	-	-	-	-
102. Wyandotte Municipal Power Plant[a]	534	1,300	700	7	18	-	-	-	-	-	-	-	-	-	-	-
Detroit Public Lighting Commission																
103. Mistersky Power Plant[a]	2,590	4,960	67	27	2,666	-	-	-	-	-	-	-	-	-	-	-
104. L. J. Schrenk Heating Plant[a]	353	250	130	6	20	-	-	-	-	-	-	-	-	-	-	-
105. Herman Kiefer Heating Plant[a]	232	200	86	4	13	-	-	-	-	-	-	-	-	-	-	-
Wayne County total	83,418	360,134	100,336	1,373	6,397	2,935	739	805	271	2,472	55,835	19,959	1,525	6,064	32,487	34,968
Oakland County																
106. General Motors Corp.	141	130	85	4	13	22	6	11	3	56	2,888	664	111	-	2,467	6,696
107. Edward Levy Co.	-	-	-	-	-	-	-	-	-	-	127	-	-	-	-	-
108. Southeast Oakland Co. Incinerator Authority	-	-	-	-	-	493	145	145	22	73	-	-	-	-	-	-
Oakland County total	141	130	85	4	13	515	151	156	25	129	3,015	664	111	-	2,467	6,696

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967

(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
														HC		
	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	HC	CO	Particulates	SO_x	NO_x	Process	Solvent	CO
Macomb County																
Chrysler Corp.																
109. Warren Truck Assembly Plant	875	950	500	25	75	10	-	1	19	43	-	-	-	-	506	-
110. Sterling Stamping Plant	101	1,531	26	13	39	-	-	-	-	-	-	-	-	-	-	-
Ford Motor Co.																
111. Transmission and Chassis Div.	190	2,494	486	24	72	-	-	-	-	-	-	-	-	-	-	-
112. Transmission and Chassis Div.	30	196	184	1	1	-	-	-	-	-	-	-	-	-	-	-
113. Utica Trim Plant	141	176	128	5	17	-	-	-	-	-	-	-	-	-	-	-
114. R. C. Mahon Co.	-	-	8	-	-	-	-	-	13	-	-	-	-	-	437	-
115. LTV Aerospace Corp.	196	271	200	10	30	1	-	-	-	2	-	-	-	-	-	-
116. Detroit Army Arsenal	2,040	783	326	16	48	14	-	10	4	74	-	-	-	-	-	-
117. Michigan Army Missile Plant	820	518	210	11	32	9	2	3	-	39	-	-	-	-	-	-
118. Selfridge Air Force Base	640	177	103	56	266	305	19	200	96	1,620	-	-	-	-	-	-
Macomb County total	5,033	7,096	2,171	161	580	339	21	214	132	1,778	-	-	-	-	943	-
St. Clair County																
119. Diamond Crystal Salt Co.	250	1,402	690	34	102		-	-	-	-	-	-	-	-	-	-
120. Ainsworth Manufacturing Co.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	131	-
121. St. Clair Rubber Co.	-	-	14	-	-	-	-	-	-	-	-	-	-	-	599	-
122. Chrysler Corp., Marysville Depot	186	561	103	5	15	38	-	-	65	69	-	-	-	-	381	-
123. Prestolite Wire and Cable	1	-	15	-	-	-	-	-	-	-	4	-	-	-	160	-
124. Grand Trunk and Western Terminal	239	173	23	26	100	13	-	-	11	45	-	-	-	-	21	-
125. Mueller Brass Co.	90	257	102	2	7	4	-	-	-	16	130	-	-	-	-	-
126. Peerless Div., American Cement Corp.	-	-	-	-	-	-	-	-	-	-	1,420	99	948	-	-	-
127. Dunn Paper Co.	484	234	124	6	17	-	-	-	-	-	-	-	-	-	-	-
Detroit Edison Co.																
128. Marysville Power Plant[a]	9,820	35,200	7,160	72	180	-	-	-	-	-	-	-	-	-	-	-
129. Port Huron Paper Power Plant	542	600	373	4	9	-	-	-	-	-	-	-	-	-	-	-
130. St. Clair Power Plant[a]	8,613	230,200	36,330	363	906	-	-	-	-	-	-	-	-	-	-	-
St. Clair County total	20,225	268,627	44,934	512	1,336	55	-	-	76	130	1,554	99	948	-	1,292	-
United States total	108,817	635,987	147,526	2,050	8,326	3,844	911	1,175	504	4,509	60,404	20,722	2,584	6,064	37,189	41,664

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967

(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	HC		CO
														Process	Solvent	
Canada:																
Essex County																
1. Calvert of Canada	27	409	85	2	2	14	-	9	26	73	430	-	-	-	128	-
2. Amherst Quarries	-	-	-	-	-	-	-	-	-	-	2,130	-	-	-	-	-
3. Allied Chemical	4,422	3,428	1,824	100	274	-	-	-	-	-	-	-	-	-	35	-
4. Canadian Rock Salt	1	2	3	-	-	1	-	-	1	3	100	-	-	-	-	-
5. Maretette Bros.	-	2	1	-	-	-	-	-	-	-	143	-	-	-	-	-
6. Plasticast	1	15	-	-	-	-	-	-	-	-	-	-	-	-	149	-
7. J. Clark Keith Generating Plant	695	15,840	3,970	40	99	-	-	-	-	-	-	-	-	-	-	-
8. Canadian Salt	35	589	115	3	3	-	-	-	-	-	-	-	-	-	-	-
9. Shell (Storage Tanks)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	249	-
10. Gulf (Storage Tanks)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	435	-
11. University of Windsor	11	334	43	1	1	-	-	-	-	-	-	-	-	-	-	-
12. Ford Motor Co. (Windsor Operations)	6,370	1,964	1,428	69	207	-	-	-	-	-	582	-	-	-	-	640
13. Chrysler (Truck Assembly Plant	7	265	52	1	1	-	-	-	-	-	-	-	-	-	-	-
14. Chrysler (Foundry)	2	33	13	-	-	-	-	-	-	-	4,430	-	-	-	14	-
15. Imperial Oil (Storage Tanks)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	259	-
16. Chrysler (Boiler Plant)	488	831	624	6	16	-	-	-	-	-	-	-	-	-	2,754	-
17. Texaco (Storage Tank)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	525	-
18. Dominion Forge	204	411	219	8	20	-	-	-	-	-	-	-	-	-	-	-
19. General Motors Trim	9	27	129	1	1	-	-	-	-	-	-	-	-	-	-	-
20. Hiram Walker	768	1,825	605	30	90	-	-	-	-	-	42	-	-	-	-	-
Essex County total	13,040	26,060	9,026	261	714	15	-	9	27	76	7,857	-	-	-	4,548	640
Kent County																
21. Motor Wheel Corp. of Canada	6	106	21	1	1	-	-	-	-	-	-	-	-	-	114	-
22. International Harvester	14	199	50	1	1	-	-	-	-	-	-	-	-	-	457	-
23. Libby-McNeil and Libby	14	185	42	1	1	-	-	-	-	-	-	-	-	-	1	-
24. Canada and Dominion Sugar	63	463	260	13	39	-	-	-	-	-	-	-	-	-	-	-
25. Greenmelk	1	13	18	-	-	-	-	-	-	-	320	-	-	-	-	-
Kent County total	98	966	391	16	42	-	-	-	-	-	320	-	-	-	572	-

Table 3-3 (continued). POINT SOURCE EMISSIONS IN PORT HURON - SARNIA AND DETROIT - WINDSOR AREA, 1967
(tons/yr)

Source	Fuel combustion					Refuse disposal					Process losses					
														HC		
	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	HC	CO	Partic-ulates	SO_x	NO_x	Process	Solvent	CO
Lambton County																
26. Sombra Township Dump	-	--	--	-	-	23	-	16	43	122	-	-	-	-		-
27. Chinook Chemicals	8	120	26	1	1	-	-	-	-	-	-	-	-	-	-	55
28. C.I.L. Power House	48	626	151	4	4	-	-	-	-	-	-	-	-	-	-	-
29. C.I.L. Ammonia Plant	47	1	544	-	1	-	-	-	-	-	735	-	-	-	-	-
30. Ethyl Corp.	-	53	14	-	-	-	-	-	-	-	-	-	-	486	-	-
31. Shell Canada (Sarnia 32. Refinery)	431	12,738	1,498	36	36	-	-	-	-	-	470	4,368	-	-	2,850	-
32. Dupont (St. Clair River Works)	63	1,189	194	7	6	3	-	2	5	14	-	-	-	-	2,800	-
33. Fiberglas (Glass Furnaces)	26	395	109	2	2	240	-	165	450	1,275	311	374	-	-	85	-
34. Sun Oil Boiler Plant (Refinery)	235	2,071	1,161	16	17	-	-	-	-	-	525	164	6	-	432	8,270
35. Dow Chemical (Steam Process)	1,857	14,187	2,874	123	332	-	-	-	-	-	-	387	-	-	1,765	58
36. Dow Chemical (Process)	4	-	45	-	-	-	-	-	-	-	-	-	-	-	2,116	-
37. Polymer	12	-	143	-	-	-	-	-	-	-	-	360	-	-	730	-
38. Dow Chemical (Process)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39. Dow Chemical (Process)	3	-	31	-	-	-	-	-	-	-	-	-	-	-	7,585	-
40. Polymer	18,268	25,056	7,110	295	886	-	-	-	-	-	-	35	340	-	13,485	-
41. Cabot Carbon	70	590	836	-	2	-	-	-	-	-	-	290	-	-	3,540	55,200
42. Imperial Oil (Refinery)	217	266	172	2	2	-	-	-	-	-	-	5,350	-	-	737	-
43. Polymer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	590	-
44. Imperial Oil (Refinery)	156	1,324	727	11	12	-	-	-	-	-	-	-	-	-	-	-
45. Imperial Oil (Refinery)	630	7,759	2,179	16	17	-	-	-	-	-	910	5,625	-	-	985	90,000
46. Imperial Oil (Storage Tanks)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5,350	-
47. Imperial Oil (Refinery)	133	1,625	469	11	11	-	-	-	-	-	-	403	-	-	636	-
48. Holmes Foundry	1	2	226	-	-	-	-	-	-	-	225	-	-	-	-	-
Lambton County total	22,208	68,002	18,509	524	1,329	266	-	183	498	1,411	3,176	17,356	346	486	43,686	153,583
Canada total	35,346	95,028	27,926	801	2,085	281	-	192	525	1,487	11,353	17,356	346	486	48,806	154,223
Study total	144,163	731,015	175,452	2,851	10,411	4,125	911	1,367	1,029	5,996	71,757	38,078	2,930	6,550	85,995	195,887

[a] Company withheld data necessary for emission calculations; estimates made based on data from publications and State and local Air Pollution Control agencies.

[b] Rough estimate based on 0.1 percent of coal charged in coke ovens or slag crushed and stockpiled.

Industrial process losses in the U. S. yielded 24 percent of the total particulate emissions. They were the source of 7 percent of the HC emissions, the major portion of which came from solvent losses from spray-painting operations.

In the Canadian area, industrial process losses constituted 23 percent of the particulate emissions, 15 percent of the SO_x emissions, only 1 percent of the NO_x emissions, 58 percent of the HC emissions, and 63 percent of the CO emissions for the area.

3.7 POINT SOURCES

As previously defined, a point source of air pollution is considered to be a single source that emits a total of 100 or more tons per year of any pollutant from its various processes. Included among the point sources in this study are municipal incinerators, steam-electric power plants, heating plants, government military facilities, and industrial plants.

Among the industries reported as point sources are several chemical plants, steel plants, oil refineries, many automobile factories, and related parts suppliers. Several metal fabricators are included in view of HC losses from painting operations.

The point sources for the area are listed in Table 3-3 with the quantities of pollutants emitted from the combustion of fuel and refuse and from process losses. The point sources are located in Figure 3-2.

In the Canadian area, 47 of the 48 point sources listed are industrial plants; the other is a steam-electric utility. The point source emissions contributed 89 percent of the particulates, 84 percent of the SO_x, 69 percent of the NO_x and HC emissions, and 64 percent of the CO emissions for the area. Thus, well over two-thirds of the pollution in the Canadian area is generated by these 48 sources.

In the U. S. area, there are 98 industrial point sources, 18 power and heating plants, 5 governmental or institutional sources, and 9 municipal incinerators. Together, these 130 point sources contributed 68 percent of the particulate emissions, 83 percent of the SO_x, and 50 percent of the NO_x emissions in the U. S. area. They accounted for only 8 percent of the HC and 3 percent of the CO emissions.

3.8 EMISSION CHANGES BETWEEN 1967 AND 1971

Listed in Table 3-4 are changes in emissions from individual point sources that have already taken place or are proposed for implementation by 1971. The emission changes consist of reductions due to installation of control equipment, discontinuation of some processes, and increases due to new plants, new processes, and new additions that have been made to date. Only changes known to be planned for production and control techniques are included. These planned changes can be determined only for individual plants, i. e., point sources. Table 3-5 gives the total percentage changes by year, based on the 1967 emissions from point sources in the U. S. and Canada.

A reduction of 39 percent in particulate emissions from the point sources in the U. S. area has been projected for 1971. Most of this reduction is to be effected in the emissions from power plants, steel plants, automobile manufacturers,

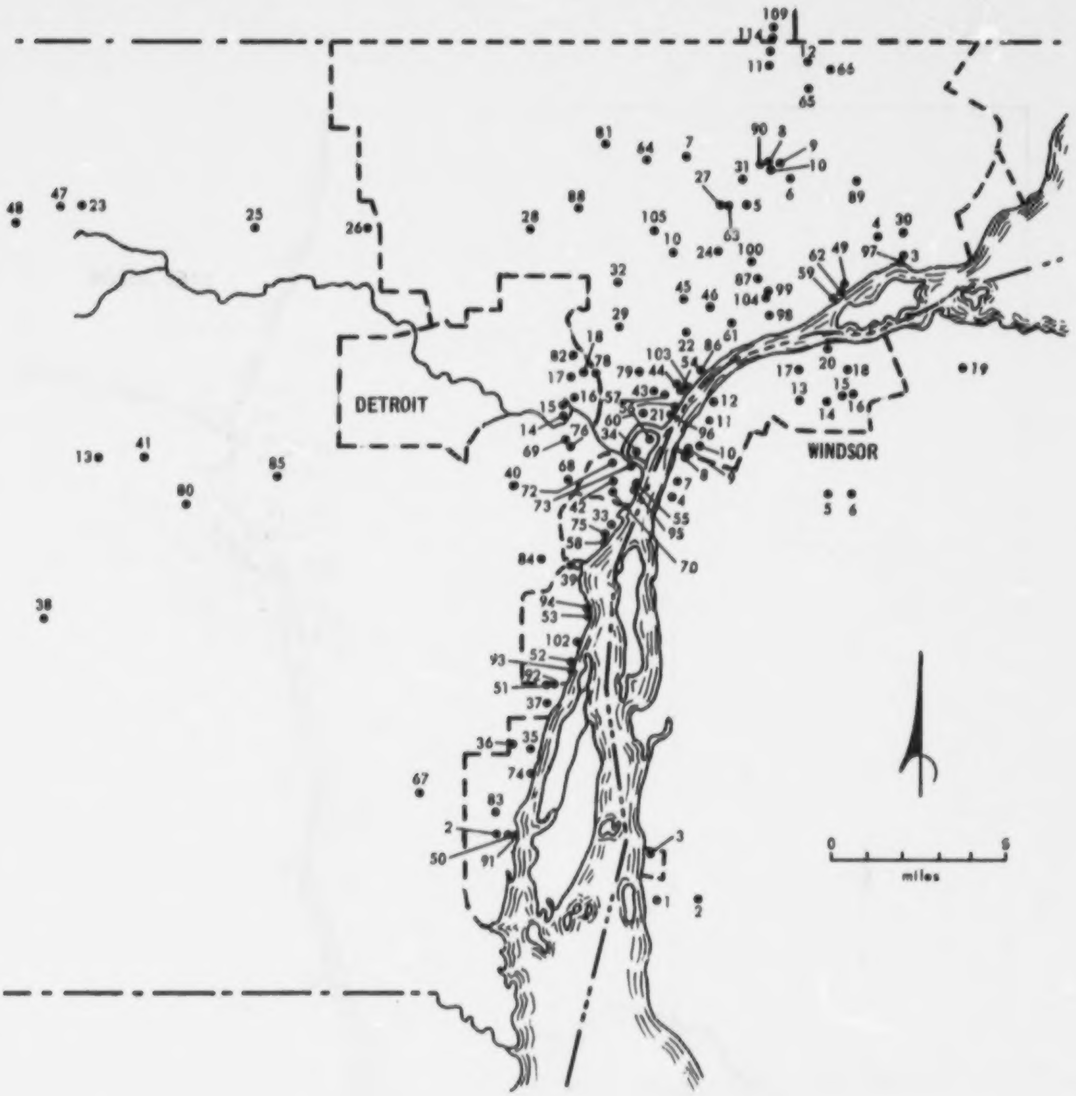

Figure 3-2. Point source locations in Port Huron—Sarnia and Detroit—Windsor areas.

and chemical plants. Emissions of SO_x and NO_x are expected to increase by 10 and 6 percent, respectively. This is primarily as a result of the new unit added to the Detroit Edison Power Plant at St. Clair.

A reduction of 57 percent in particulate emissions from point sources in the Canadian area has been projected for 1971; 39 percent of this reduction is from the proposed conversion of boilers from coal to gas in 1970 by the Polymer Corporation. Emissions of SO_x and NO_x from point sources will be more than doubled when all four units of the Ontario Hydroelectric Power Plant, in the Sarnia area, are on line by 1971.

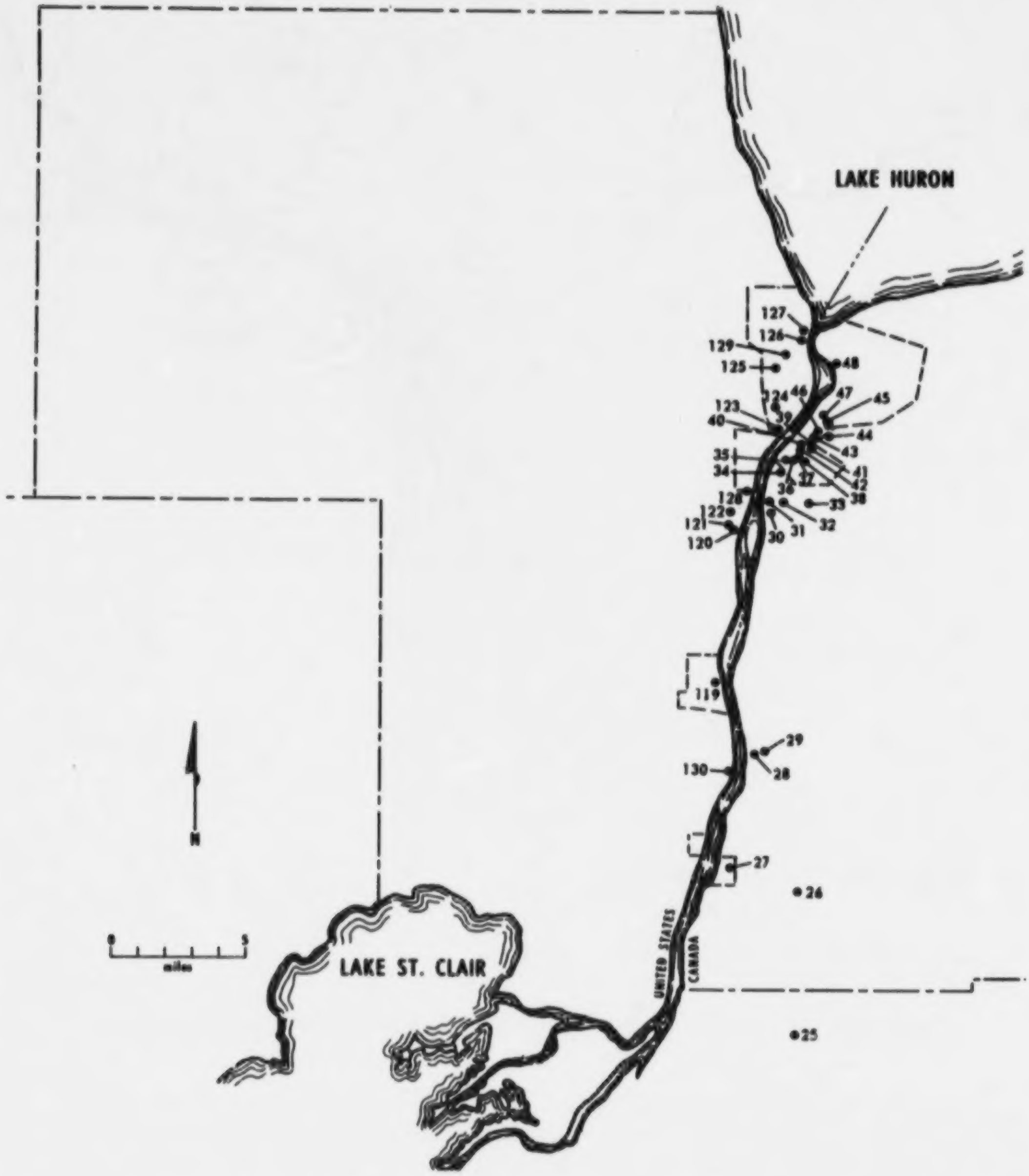
LAKE HURON
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Figure 3-2 (continued). Point source locations in Port Huron—Sarnia and Detroit—Windsor areas.

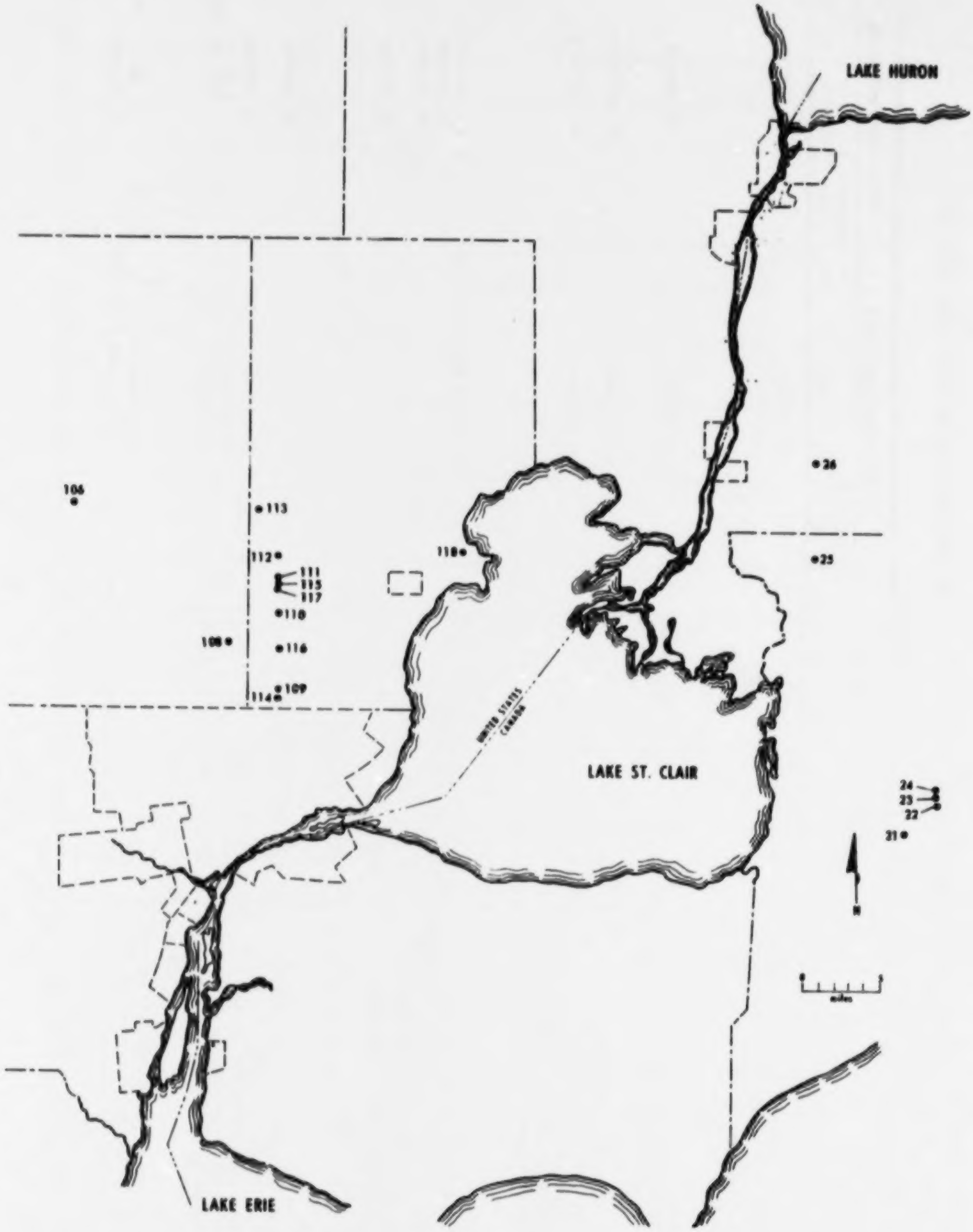
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Figure 3-2 (continued). Point source locations in Port Huron—Sarnia and Detroit—Windsor areas.

Table 3-4. PROPOSED EMISSION CHANGES TO BE IMPLEMENTED BETWEEN 1967 AND 1971

(tons/yr)

U.S. facility and control method	1968 total emissions					1969 total emissions					1970 total emissions				
	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO
American Motors Co. Electrostatic precipator (ESP) was installed on boiler in 4th quarter of 1968. Particulate emission control increased from 80 to 99 %.	4	129	27	34	170		No change					No change			
Allied Chemical Corp.															
Industrial Chemical Div. - Power plant and soda ash manufacturing to shut down by 1969.	0	0	0	0	0		No change					No change			
Semet Colvay Process - Build new coke ovens to replace old by 1969.	818	684	174	-	-		No estimate					No estimate			
Industrial Chemicals Div. - Sulfuric acid manufacture plant to install 20 ft stack. Rework towers and collectors by 1969.	85	2,700	-	-	-		No estimate					No estimate			
Ford Motor Co.															
Power Plant - add ESP to six boilers.	4,902	15,276	8,082	111	299	1,117	15,276	8,082	111	299		No estimate			
Sinter Plant - Add ESP in 1st quarter 1969.	875	-	-	-	-	175	-	-	-	-		No change			
Dearborn Iron Foundry - Add high energy venturi scrubbers 2nd quarter 1969.	2,643	-	-	-	-	196						No change			
Dearborn Specialty Foundry - Venturi scrubbers to be added.	638	-	-	-	-	109	-	-	-	-		No change			
Schaefer Rd. Dump - Discontinue by 1970.	166	-	114	52	880	41	-	28	13	220	-	-	-	-	-
Chrysler															
Detroit Forge - Convert two pulverized-fuel boilers to gas by 1969.	1,030	147	257	2	6	6	-	71	-	-		No change			
Huber Foundry - Refurbish collectors.	93	184	96	-	-		No change					No change			
Mack Ave. Stamping - Convert to gas by 1970.	691	439	262	12	36		No change				63	-	92	-	-
Hamtramck Assembly - Convert to gas by 1970.	1,928	2,090	110	4,806	28		No change				29	-	306	4,795	
General Motors															
Diesel Engine Div. - Waste heat boiler and afterburner on engine test stand by 1970.	640	2	64	78	19		No change				10	2	64	78	19
Detroit Forge - Install ESP on four pulverized-fuel boilers 1st quarter 1969. Assume 99.5 % efficiency.	2,273	4,391	1,650	82	246	160	4,391	1,650	82	246		No change			

Table 3-4 (continued). PROPOSED EMISSION CHANGES TO BE IMPLEMENTED BETWEEN 1967 AND 1971

(tons/yr)

U.S. facility and control method	1968 total emissions					1969 total emissions					1970 total emissions				
	Partic-ulate	SO_x	NO_x	HC	CO	Partic-ulate	SO_x	NO_x	HC	CO	Partic-ulate	SO_x	NO_x	HC	CO
Kelsey Hayes Co. - Cupola - Install after-burners and change accessory parts in collector system by 1970.	405	785	287	14	39		No change					No change			
Peerless Cement															
Jefferson Plant - Phase out and build new plant 1972.	1,001	319	987	2	6		No change					No change			
Brennan Plant - Revamp collector system.	1,280	55	530	-	-		No change					No change			
Great Lake Steel															
Open Hearths - Replace with two basic oxygen furnaces (BOF) by mid-1970.	9,065	-	-	-	-		No change				1,200	-	-	-	-
Sintering - Hot gas discharge - install ESP by 1971.	4,550	258	-	-	-		No change					No change			
Clinker discharge - add dry collectors by 1971.	5,000	-	-	-	-		No change					No change			
Coke Ovens - build new ovens to replace old 1st quarter 1970.	2,660	4,180	-	-	-		No change					No estimate			
Two new electric furnaces 600,000-ton capacity in 1968.	60	-	-	-	-		No change					No change			
McLouth Steel - Phase out oxygen process plant #1 and expand BOF plant #2 to five vessels with new Theissen dis-integrators by mid-1969. Sinter plant - Refurbish cyclones, overhaul ESP by 1970.	6,884	613	5,254	7	16		No estimate					No estimate			
DuPont - Plant shut down July 31, 1968.	-	1,100	-	-	-		No emission					No emission			
Park Davis - No. 5 boiler converted to gas by 1968.	45	47	129	1	3		No change					No charge			
Scott Paper - Convert power house to gas and oil by 1970.	1,487	2,344	1,080	54	162		No change				26	600	312	-	-
Detroit Edison															
Conners Creek - Increase collector efficiency from 75 to 90 % by mid-1969.	14,800	71,100	16,390	164	410	9,550	71,100	16,390	164	410	4,300	71,100	16,400	200	400

Table 3-4 (continued). PROPOSED EMISSION CHANGES TO BE IMPLEMENTED BETWEEN 1967 AND 1971 (tons/yr)

U.S. facility and control method	1968 total emissions					1969 total emissions					1970 total emissions				
	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO
Trenton Channel - Increase efficiency on four units from 98 to 99.6 % by mid-1968. Modification to auxiliary gas and oil by 1970.	3,310	45,900	13,475	135	337	2,725	45,900	13,475	135	334	725	45,900	13,475	135	337
Pennsalt Power Plant - Increase efficiency from 80 to 99.6 % on two boilers by mid-1968.	1,700	3,800	1,700	17	43	100	3,800	1,700	17	43	No change				
Wyandotte North - Boilers 5, 6, 4, and 8 converted from underfeed stoker to gas; boiler 7 converted from pulverized coal to gas; ESP installed on boilers 9 and 10. Efficiency 99.6 % by mid-1969.	14,510	10,800	4,130	41	103	7,302	9,400	3,700	35	89	95	7,950	3,260	30	74
Marysville - Increase collection efficiency on four boilers from 98 to 99.6 %.	9,820	35,200	7,160	72	180	7,650	35,200	7,160	72	180	7,650	35,200	7,160	72	180
Port Huron Paper - New pulverized-fuel boiler being installed. Will have 99.6 % collection. Existing boilers convert to gas.	542	600	373	4	9	No change					45	2,565	477	4	11
Beacon St. Heating - Install 93 % efficient mechanical collectors on four underfeed boilers by mid-1969.	2,590	5,200	2,880	29	72	1,490	5,200	2,880	29	72	390	5,200	2,880	29	72
St. Clair - Install new unit #7 on line 1970.	8,613	230,200	36,330	363	906	No change					10,100	311,710	50,630	506	1,263
Mueller Brass Co. - Converted coal boiler to natural gas, 1969.	224	257	102	2	23	No change					138	-	54	-	16
Dunn Paper Co. - Installed cyclone collector	484	234	124	6	17	No change					97	234	124	6	17
Diamond Crystal Salt Co. - Converted underfeed stoker and pulverized-coal unit to a spreader stoker - converted two PC units to natural gas.	250	1,402	690	34	102	No change					250	528	370	26	6
Wyandotte Municipal Power Co. - Install gas turbine and place two spreader stokers on standby.	534	1,300	700	7	18	No change					16	-	190	-	-
Lincoln Park - Stop residential and commercial rubbish burning by 1970.	No estimate					No estimate					No estimate				

Table 3-4 (continued). PROPOSED EMISSION CHANGES TO BE IMPLEMENTED BETWEEN 1967 AND 1971
(tons/yr)

U.S. facility and control method	1968 total emissions					1969 total emissions					1970 total emissions				
	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO
Detroit - Install auxiliary gas burners and barometric dampers on all 4,000 existing apartment flue-fed incinerators - approximately 50 % now complete. Remainder by 1971.		No estimate					No estimate					No estimate			
U.S. Rubber Tire - convert pulverized-fuel boilers to gas 1st quarter 1970.	1,466	1,976	1,300	65	195		No change				33	-	392	-	-
Export Processing - Install afterburners on spray paint line.	7	47	22	206	1	7	47	22	Reduced	1	7	47	22	1	1
Wolverine Aluminum Corp. - Install gas-fired fume burner by 1970.	2	-	-	1,015	5		No change				2	-	-	-	5
Huron Valley Steel - Install venturi scrubber on cupola by 1970.	619	26	47	1	8,751		No change				115	26	47	1	8,751
Wayne Co. General Hospital - Refractory cover lower boiler tubes by 1970.	404	572	350	18	54		No change					No estimate			
Wyandotte Chemical Corp. - Stop open burning 1968.															
North - Correct uncontrolled 15 % of exhaust gas by 1971.	746	-	45	-	12,585		No change					No change			
South Plant - Cement - Refurbish ESP by 1969. Lime Plant - Phase out use - no date.	1,536	132	89	-	21,280	608	132	89	-	21,280		No change			
Lear Siegler - Transfer auto seat manufacturing from Detroit.	4	2	37	150	1	4	2	37	50	1		No change			
Champion Spark Plug - Moving to new building.	186	-	27	-	3		None					None			
Michigan Army Missile Plant - Convert to gas by 1971.		No change					No change					No change			
Selfridge AFB - Convert to gas by 1969 - Stop open burning 1972.	945	196	303	152	1,886	311	19	260	96	1,620		No change			
Total change from previous year, tons	-6,701	-4,811	-2,256	-236	-259	-30,384	-2,824	-772	-203	-919	-30,019	+73,345	+11,418	-1,218	-425

Table 3-4 (continued). PROPOSED EMISSION CHANGES TO BE IMPLEMENTED BETWEEN 1967 AND 1971 (tons/yr)

Canadian facility and control method	1968 total emissions					1969 total emissions					1970 total emissions				
	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO	Particulate	SO_x	NO_x	HC	CO
Lambton Co., Ontario															
Ontario Hydro - New coal-fired power plant.	-	-	-	-	-	-	-	-	-	-	1,230	160,000	38,300	380	960
Holmes Foundry - Multicyclone being installed.	226	2	226	-	-	176	2	226	-	-	100	2	226	-	-
Imperial Oil Canada Ltd. - New coker complex.	1,540	13,384	2,179	1,001	90,017	No change					995	13,384	2,179	1,001	917
Polymer Corp. - Convert coal-fired boilers to gas. Other improvements to be made by 1971.	18,240	25,010	6,745	295	885	No change					21	2,367	1,640	-	3
Kent Co.															
Canada Dominion Sugar - Closed down.	No emissions					No emissions					No emissions				
Essex Co.															
Chrysler of Canada, Ltd. - Closed down 1970.	4,432	33	13	14	-	No change					Shut down - early 1970				
Ford Motor Company - Install wet scrubber 95 % efficiency on acid and basic cupolas by 1968. Add bag filters and afterburner 1970.	6,792	1,964	1,428	69	847	No change					6,570	1,964	1,428	69	307
Allied Chemical Corp. - Reduction of particulate emissions.	4,422	3,428	1,824	135	274	No change					642	3,428	1,824	135	274
Calvert of Canada - Convert to natural gas.	471	409	94	156	75	No change					444	0	876	154	73
Plasticast - Closed down.	1	-	15	149	-	No change					-	-	-	-	-
Hiram Walker - New tall stack and ESP	810	1,825	605	30	90	No change					342	1,825	605	30	90
Total change from previous year, tons	-223	-463	-260	-13	-39	-50	0	0	0	0	-26,540	+136,915	+33,949	-80	-89,564

Table 3-5. PROJECTED PERCENTAGE CHANGES IN POINT SOURCE EMISSIONS, 1968 THROUGH 1970

Pollutant	1967 total, tons		1968 change, %		1969 change, %		1970 change, %		Total change by 1971, %	
	U. S.	Canada	U. S.	Canada	U. S.	Canada	U. S.	Canada	U. S.	Canada
Particulates	173,065	46,980	-3.9	-0.5	-17.6	-0.1	-17.3	- 56.5	-38.8	- 57.1
SO_x	657,620	112,384	-0.7	-0.2	- 0.4	0.0	+11.1	+121.8	+10.0	+121.6
NO_x	151,285	28,464	-1.5	-0.9	- 0.5	0.0	+ 7.5	+119.3	+ 5.5	+118.4
HC	45,807	50,618	-0.5	0.0	- 0.4	0.0	- 2.7	- 0.2	- 3.6	- 0.2
CO	54,599	157,795	-0.5	0.0	- 1.7	0.0	- 0.8	- 56.7	- 3.0	- 56.7

4. TRANSBOUNDARY FLOW OF AIR POLLUTANTS

Climatological and meteorological survey data discussed in Section 1 have indicated the effects of meteorological factors - primarily the wind direction - on the transport of air pollutants across the international boundary. Such indications are qualitative only. Specific association of pollution at a receptor site with a particular source or group of sources is not possible unless the source is either unique as to the pollutant it emits, as might occur in the case of an odor (see Section 3), or isolated geographically. By combining pollution measurements with coincident wind data, inference can be drawn as to the general sector or origin of pollution affecting a particular receptor location. Graphic displays of such combined data, called pollution roses, can be made for occurrences of pollution concentrations in excess of a selected value; alternately, frequency distributions may be tabulated by wind directions.

Source emission inventory data may be used with meteorological data to estimate quantitatively the contribution of individual or groups of point or area sources to the pollution at specific receptor sites. A mathematical dispersion model[1] is used in making such an estimation; and the best verification is obtained when time-averaged, i.e., seasonal or annual mean, emission rates are used to estimate average concentrations for corresponding periods. Both pollution roses and dispersion models have been used to evaluate the extent of transboundary flow of air pollution in the Port Huron - Sarnia and Detroit - Windsor areas. In addition, an airplane was used to make measurements of the flux of certain pollutants through the vertical plane along the international boundary. Two sets of flux measurements were selected for illustration, one in the Detroit—Windsor area with a westerly wind carrying pollution from the U.S. to Canada, and one in the Port Huron—Sarnia area with a northeasterly wind carrying pollution from Canada to the U.S.

The significance of transboundary flow of air pollution is discussed below on the basis of interpretations of the preceding analyses and measurements.

4.1 POLLUTION ROSES

Pollution roses were constructed for stations having measurements of suspended particulates, soiling index, and/or SO_2 coincident with wind direction at or near the station. Furthermore, selection of stations for pollution roses was based on their proximity to the boundary and their spacing along the boundary. For suspended particulates, wind roses were constructed showing the percentage frequency of occurrence of each wind direction for all hours when the daily average suspended-particulate concentration exceeded an arbitrary value considered representative of relatively dirty air for each station. To reduce the inconsistencies associated with light and variable winds, only 24-hour periods when the average wind speed exceeded 3 miles per hour were considered in the roses for particulates. Because of the nature of the particulate roses and the wide range of concentrations in the area, it was not possible to choose a single value to represent relative dirtiness throughout the area. The pollution roses for soiling index and SO_2 were prepared by determining, for each wind direction, the percentage of time that pollution levels exceeded an arbitrarily selected, relatively high concentration value. The pollution roses for the Detroit - Windsor area are given in Figures 4-1, 4-2, and 4-3, and for the Port Huron - Sarnia area in Figures 4-4, 4-5, and 4-6.

Interpretation of graphic or tabular data from pollution roses must be made with care since sources both near and distant in a sector will contribute to local pollution. Among other factors, the following affect interpretation:

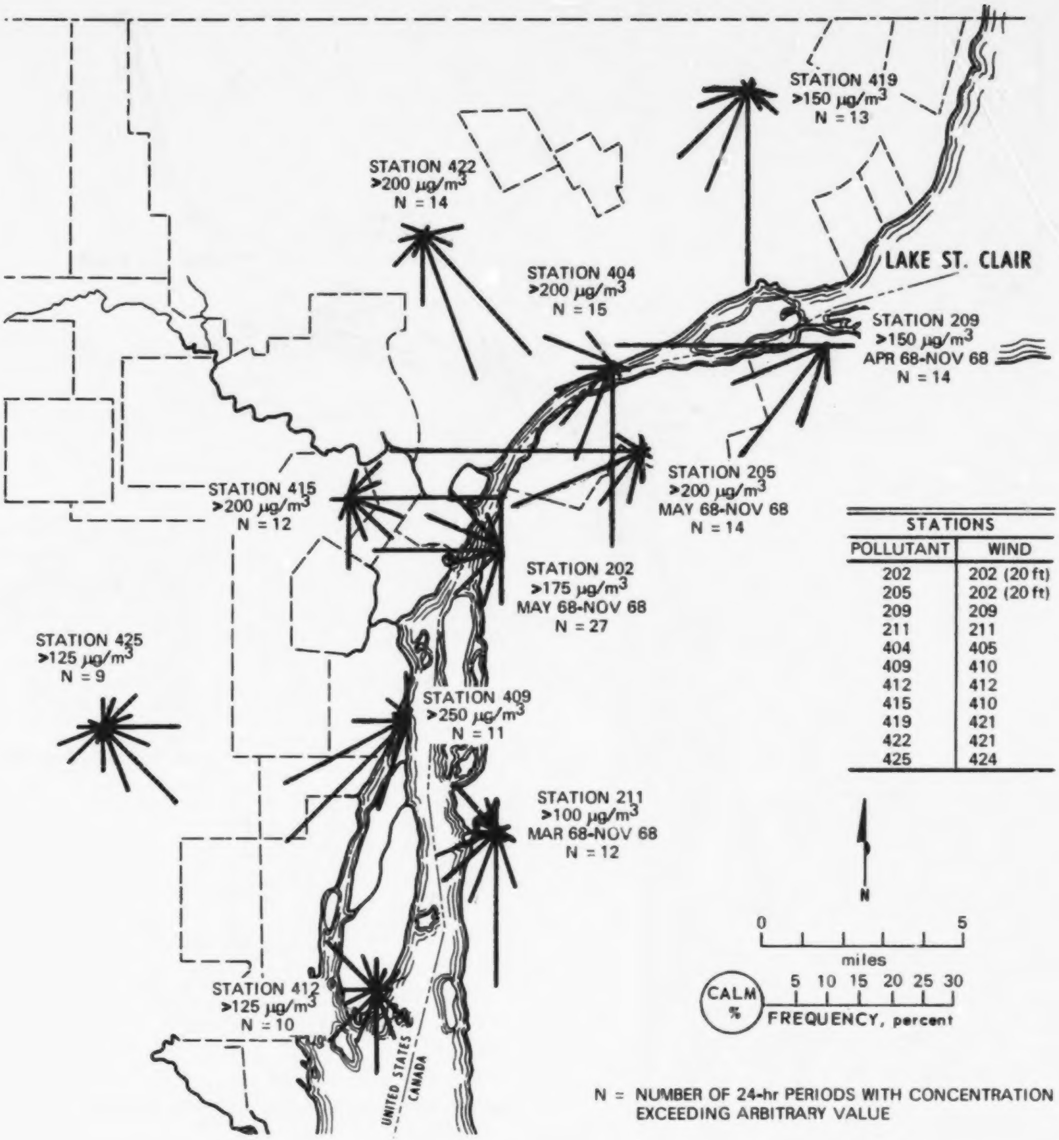
1. The capacity of the air to disperse pollutants varies with wind speed and stability, both of which differ with wind direction.
2. At any location, certain wind directions will occur more frequently than others. Such variations will introduce some bias into pollution roses.
3. The height and distance of a source affect the amount of pollution reaching a receptor.

Stations on the banks of the Detroit River offer the most unequivocal evidence of transboundary flow of particulates. Stations 205 and 209 in Canada each have high frequencies of occurrence of west winds during periods of high suspended-particulate concentrations; this indicates that Detroit is the source region. A portion of the particulate loading, however, would be contributed from sources located in Windsor between the sampling station and the boundary.

The suspended-particulate roses for the Port Huron—Sarnia area (Figure 4-4) also show evidence of local source contribution. Stations 151, 160, and 161 indicate contributions from Canadian sources lying in the area between these stations. Evidence of significant cross-boundary transport is indicated at Stations 159 in Lambton County, Canada, and 307 in St. Clair County, United States. This transport is presumably from sources directly across the river in each case. In addition, several of the stations showed frequent wind directions paralleling the river during high-concentration periods. Several of these cases cannot be explained by sources in the St. Clair River vicinity, which suggests that at times appreciable particulate pollution may reach this area from the Detroit—Windsor vicinity.

Pollution roses for soiling index for the Detroit—Windsor area (Figure 4-2) emphasize the frequent occurrence of high soiling index in Detroit. Again, the riverfront stations, 403 and 404 in the U. S. and 202 in Canada, offer the most obvious evidence of transboundary flow. Both 403 and 404 show appreciable pollution from all directions including those that indicate an air trajectory over Canada. This trajectory could imply the transport of pollutants originating in the U. S., i.e., the Zug Island — River Rouge — Ecorse area, passing across a portion of Windsor and returning to the U. S., reaching sampling Stations 403 and 404. The relatively high frequency of occurrence of pollution at Station 202, associated with northwesterly winds, tends to indicate as the source the heavily industrialized area of Zug Island and the lower Detroit River area. The data for Station 406, which is located west of this industrialized area, emphasize the effects of local sources on pollution roses.

The soiling index rose for Station 301 (Figure 4-5) in Port Huron suggests significant transboundary flow from sources in the petroleum-related industrial complex south of Sarnia. At Station 303 in Marysville, the occurrence of pollution with east, but not with east-northeast or east-southeast winds, suggests an



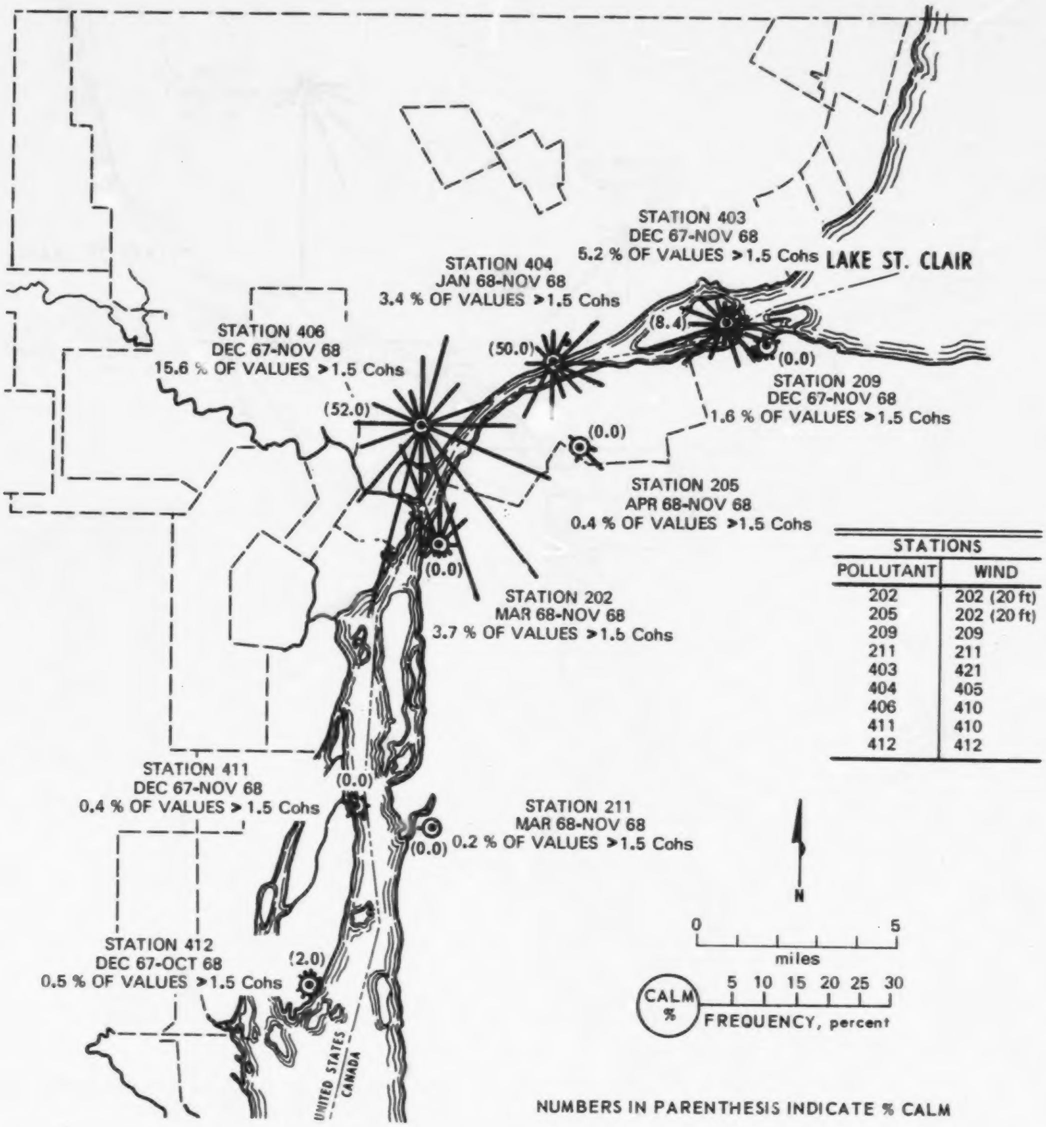
STATION 419
>150 μg/m³
N = 13
STATION 422
>200 μg/m³
N = 14
LAKE ST. CLAIR
STATION 404
>200 μg/m³
N = 15
STATION 209
>150 μg/m³
APR 68-NOV 68
N = 14
STATION 205
>200 μg/m³
MAY 68-NOV 68
N = 14
STATION 415
>200 μg/m³
N = 12
STATION 202
>175 μg/m³
MAY 68-NOV 68
N = 27
STATION 425
>125 μg/m³
N = 9
STATION 409
>250 μg/m³
N = 11
STATION 211
>100 μg/m³
MAR 68-NOV 68
N = 12
STATION 412
>125 μg/m³
N = 10
UNITED STATES
CANADA
N
0
5
miles
CALM
%
5 10 15 20 25 30
FREQUENCY, percent
N = NUMBER OF 24-hr PERIODS WITH CONCENTRATION EXCEEDING ARBITRARY VALUE

STATIONS	
POLLUTANT	WIND
202	202 (20 ft)
205	202 (20 ft)
209	209
211	211
404	405
409	410
412	412
415	410
419	421
422	421
425	424

Figure 4-1. Hourly wind roses for 24-hr periods with suspended particulate concentrations in excess of indicated values and average wind speed >3 mph, Detroit River vicinity, December 1967 through November 1968 (unless otherwise indicated).

isolated source directly across the St. Clair River in Canada. Some pollution arrived at Station 151 from the U.S. with the westerly winds, but uniformity of the distribution suggests that this station is in a generally polluted area.

In the case of SO_2 pollution (Figures 4-3 and 4-6), the data from the riverside stations, 404 in the U. S. and 202 in Canada, indicate appreciable cross-boundary flow. Station 415 is located west of the Zug Island - River Rouge industrial area and cannot be used as an indicator of air pollution flow from


STATION 403
DEC 67-NOV 68
5.2 % OF VALUES >1.5 Cohs
LAKE ST. CLAIR
STATION 404
JAN 68-NOV 68
3.4 % OF VALUES >1.5 Cohs
(8.4)
STATION 406
DEC 67-NOV 68
15.6 % OF VALUES >1.5 Cohs
(50.0)
(0.0)
STATION 209
DEC 67-NOV 68
1.6 % OF VALUES >1.5 Cohs
(52.0)
(0.0)
STATION 205
APR 68-NOV 68
0.4 % OF VALUES >1.5 Cohs
(0.0)
STATION 202
MAR 68-NOV 68
3.7 % OF VALUES >1.5 Cohs
STATION 411
DEC 67-NOV 68
0.4 % OF VALUES > 1.5 Cohs
(0.0)
STATION 211
MAR 68-NOV 68
(0.0) 0.2 % OF VALUES >1.5 Cohs
N
0
5
miles
STATION 412
DEC 67-OCT 68
0.5 % OF VALUES >1.5 Cohs
(2.0)
CALM %
5 10 15 20 25 30
FREQUENCY, percent
UNITED STATES
CANADA
NUMBERS IN PARENTHESIS INDICATE % CALM

STATIONS	
POLLUTANT	WIND
202	202 (20 ft)
205	202 (20 ft)
209	209
211	211
403	421
404	405
406	410
411	410
412	412

Figure 4-2. Soiling index pollution roses showing percent of values for each wind direction exceeding 1.5 Coh/1,000 lineal feet during period indicated for Detroit River vicinity (unless otherwise indicated).

Canada. Station 412 at the Grosse Ile Naval Air Station probably reflects flow from Amherstburg to the northeast, but the high frequency of occurrence of significant pollution from the south to southwest is probably due to the influence of local sources.

4.2 DISPERSION MODEL ESTIMATES

4.2.1 Application of Dispersion Model

A dispersion model is a mathematical description of the effects of atmospheric transport and dispersion processes on the behavior of air pollutant plumes from

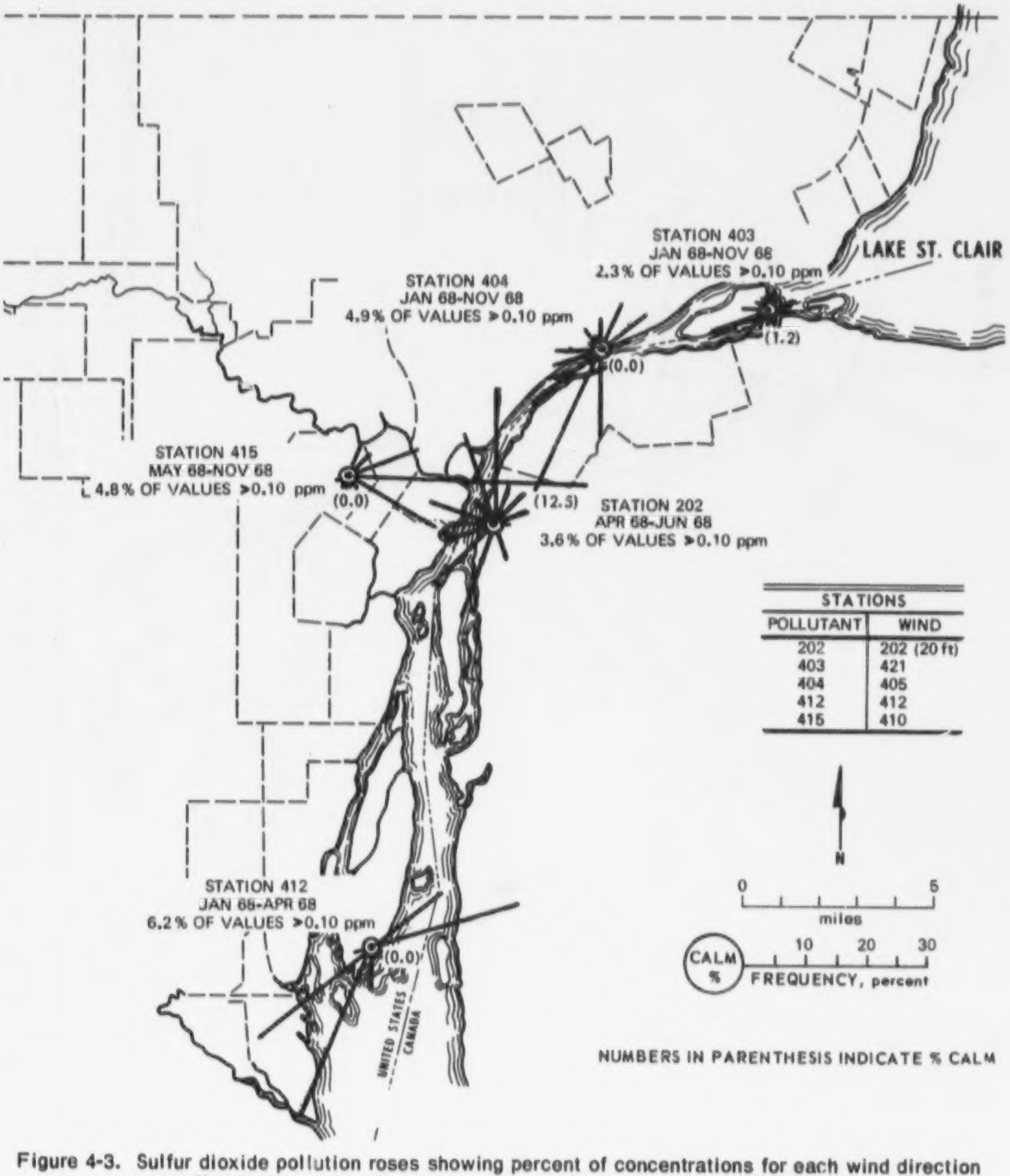
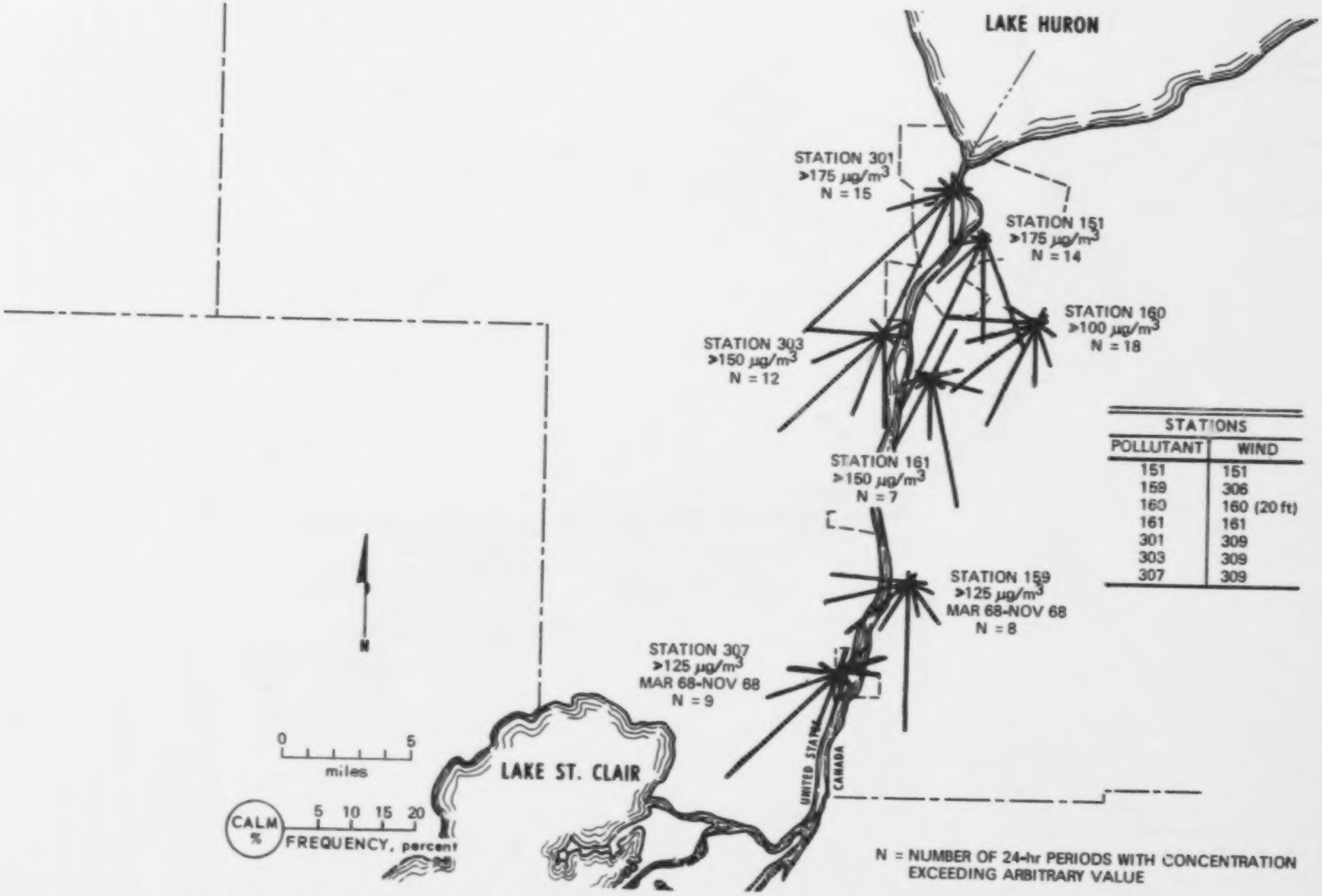

STATION 403
JAN 68-NOV 68
2.3% OF VALUES >0.10 ppm
LAKE ST. CLAIR
(1.2)
STATION 404
JAN 68-NOV 68
4.9% OF VALUES >0.10 ppm
(0.0)
STATION 415
MAY 68-NOV 68
4.8% OF VALUES >0.10 ppm
(0.0)
(12.5)
STATION 202
APR 68-JUN 68
3.6% OF VALUES >0.10 ppm
STATIONS
POLLUTANT
WIND
202 202 (20 ft)
403 421
404 405
412 412
415 410
N
0
5
miles
CALM %
10
20
30
FREQUENCY, percent
STATION 412
JAN 68-APR 68
6.2% OF VALUES >0.10 ppm
(0.0)
UNITED STATES
CANADA
NUMBERS IN PARENTHESIS INDICATE % CALM

Figure 4-3. Sulfur dioxide pollution roses showing percent of concentrations for each wind direction exceeding 0.10 ppm for periods indicated in Detroit River vicinity (unless otherwise indicated).

the time the pollutants enter the atmosphere until they reach a receptor. Specifically, the model should be capable of defining: (1) the motions of the pollutant plumes near the source; (2) modifications to the size and shape of the plumes as they are transported and dispersed downwind; and (3) based on the quantity of pollutants emitted, the concentration that will result at a known receptor.

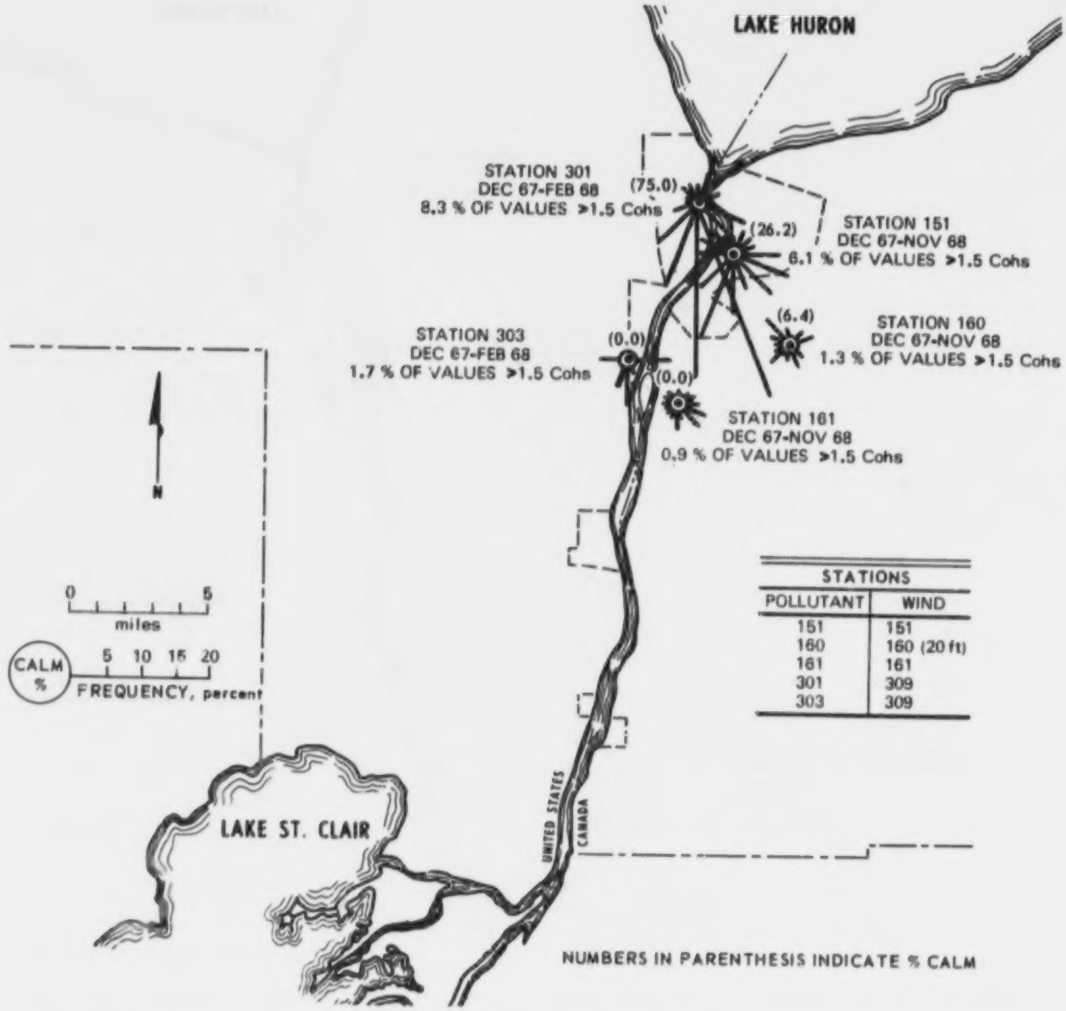
For application to the IJC Study Area, a long-term average concentration model was selected. This particular model requires as input: (1) the location and


LAKE HURON
STATION 301
>175 µg/m³
N = 15
STATION 151
>175 µg/m³
N = 14
STATION 160
>100 µg/m³
N = 18
STATION 303
>150 µg/m³
N = 12
STATION 161
>150 µg/m³
N = 7
STATION 159
>125 µg/m³
MAR 68-NOV 68
N = 8
STATION 307
>125 µg/m³
MAR 68-NOV 68
N = 9
UNITED STATES
CANADA
LAKE ST. CLAIR
N
0
5
miles
CALM %
5
10
15
20
FREQUENCY, percent

STATIONS	
POLLUTANT	WIND
151	151
159	306
160	160 (20 ft)
161	161
301	309
303	309
307	309

N = NUMBER OF 24-hr PERIODS WITH CONCENTRATION EXCEEDING ARBITRARY VALUE

Figure 4-4. Hourly wind roses for 24-hr periods with suspended particulate concentrations in excess of indicated values and average wind speed >3 mph, St. Clair River vicinity, December 1967-November 1968 (unless otherwise indicated).

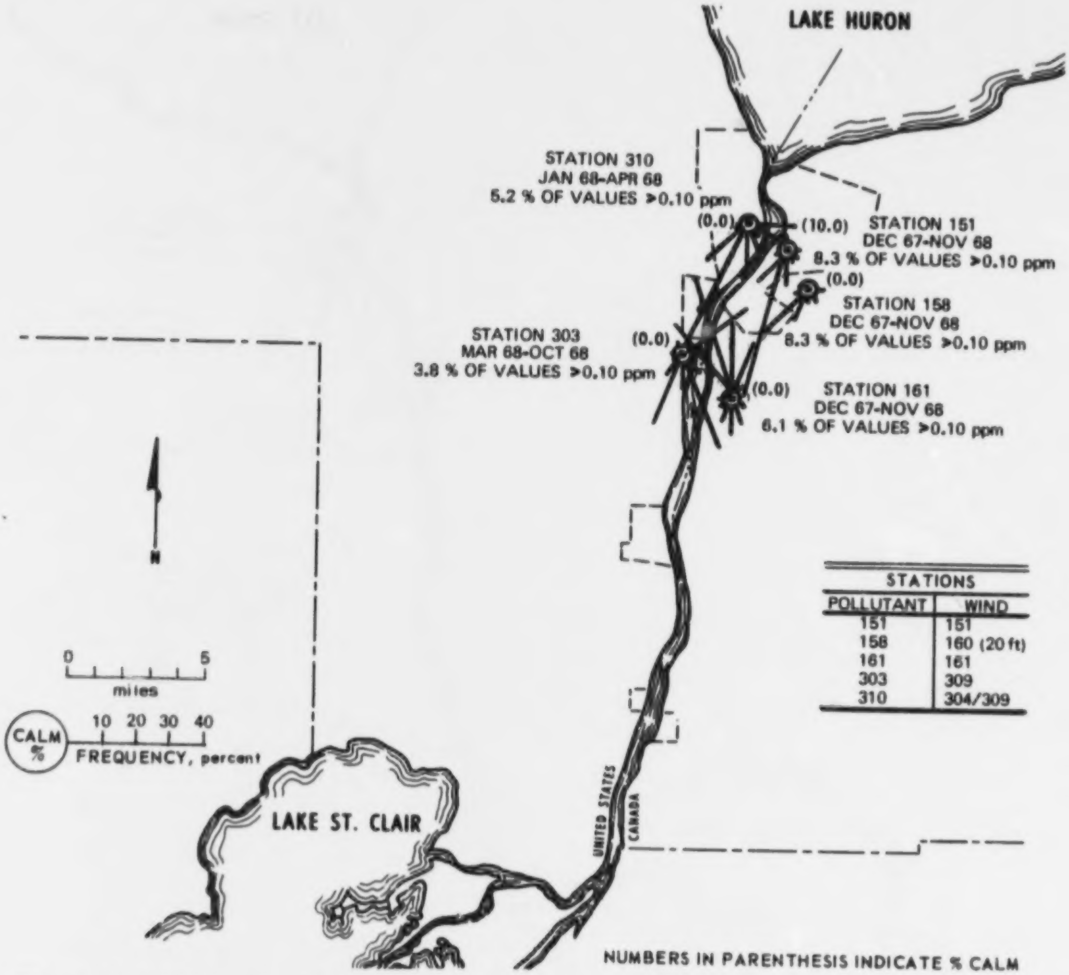

LAKE HURON
STATION 301
DEC 67-FEB 68
8.3 % OF VALUES >1.5 Cohs
(75.0)
STATION 151
DEC 67-NOV 68
6.1 % OF VALUES >1.5 Cohs
(26.2)
STATION 303
DEC 67-FEB 68
1.7 % OF VALUES >1.5 Cohs
(0.0)
STATION 160
DEC 67-NOV 68
1.3 % OF VALUES >1.5 Cohs
(6.4)
STATION 161
DEC 67-NOV 68
0.9 % OF VALUES >1.5 Cohs
(0.0)
N
0
5
miles
CALM %
5 10 15 20
FREQUENCY, percent
LAKE ST. CLAIR
UNITED STATES
CANADA
NUMBERS IN PARENTHESIS INDICATE % CALM

STATIONS	
POLLUTANT	WIND
151	151
160	160 (20 ft)
161	161
301	309
303	309

Figure 4-5. Soiling index pollution roses showing percent of values for each wind direction exceeding 1.5 Coh/1,000 lineal ft during period indicated for St. Clair River vicinity (unless otherwise indicated).

physical description of pollutant sources; (2) average rate of pollutant emission; (3) a frequency distribution of classified meteorological conditions; that is, five Pasquill-type classes of atmospheric stability, 16 wind directions, and 6 wind speeds; (4) definition of the atmospheric mixing depth; and (5) the location of receptor sites. The model determines, for each source-receptor combination, the pollutant concentration that would occur with each meteorological condition; it weights each concentration by the percentage frequency with which the associated meteorological condition occurs, and then sums the weighted concentrations for all source-receptor combinations and all meteorological conditions. By this means, the average pollutant concentration for each receptor is estimated.

The model was applied using data from the 1-year period, December 1967 through November 1968 for which a complete set of appropriate air quality and


LAKE HURON
STATION 310
JAN 68-APR 68
5.2 % OF VALUES >0.10 ppm
(0.0)
(10.0)
STATION 151
DEC 67-NOV 68
8.3 % OF VALUES >0.10 ppm
(0.0)
STATION 158
DEC 67-NOV 68
8.3 % OF VALUES >0.10 ppm
(0.0)
STATION 303
MAR 68-OCT 68
3.8 % OF VALUES >0.10 ppm
(0.0)
STATION 161
DEC 67-NOV 68
6.1 % OF VALUES >0.10 ppm
N
0
5
miles
CALM %
10 20 30 40
FREQUENCY, percent
LAKE ST. CLAIR
UNITED STATES
CANADA
NUMBERS IN PARENTHESIS INDICATE % CALM

STATIONS	
POLLUTANT	WIND
151	151
158	160 (20 ft)
161	161
303	309
310	304/309

Figure 4-6. Sulfur dioxide pollution roses showing percent of concentrations for each wind direction exceeding 0.10 ppm for periods indicated in St. Clair River vicinity (unless otherwise indicated).

meteorological data were available. The emission inventory was for 1967, and should be representative of the period selected. A study of meteorological averages (Section 1.2.3) for this period indicated that there were no significant departures from normal weather conditions. It can be assumed, therefore, that the results of this model application, when properly verified, are generally applicable to the IJC Study Area. Furthermore, the results can be used with confidence to determine the relative impact of various source categories on specific receptors.

The available data indicated that the study area encompasses two meteorological regions, which necessitated two separate model applications for proper consideration of the entire study area. The meteorological data used for the Detroit - Windsor meteorological region was collected at the Detroit City Airport, which has been shown to be a representative site for that region

(Station 421, Figure 1-5). Pasquill stability categories were determined from Weather Bureau observations by means of techniques developed by Turner.

The meteorological data used with the Port Huron - Sarnia portion of the study area were gathered at the Sarnia meteorological tower (Station 202, Figure 1-5). Pasquill stability categories were determined from lapse rate and wind speed data (Table 4-1). A frequency distribution of meteorological conditions was determined for both levels of the tower at which measurements was made. The altitude (height) used in the model to describe the transport and dispersion from a particular source was determined by the height of that specific source. For the Detroit - Windsor area, only surface data were available for the full study period.

Table 4-1. STABILITY CLASS VERSUS TEMPERATURE LAPSE RATE AND WIND SPEED AT SARNIA METEOROLOGICAL TOWER

Temperature difference (L2-L1[a]), °F	Wind speed at L2, mph				
	0 to 3	4 to 7	8 to 11	12 to 15	>15
<-6.0	A-B[b]	B	B	B-C	C
-6.0 to -1.2	B	B	C	C	D
-1.1 to -0.1	D	D	D	D	D
±0.0 to +5.0	E	E	E	E	D
>5.0	E	E	E	E	-[c]

[a] L2-L1 = temperature at 200-foot level minus temperature at 20-foot level.

[b] Stability class designations:
A - Very unstable
B - Unstable
C - Slightly unstable
D - Neutral
E - Slightly stable
F - Stable

[c] Unlikely.

The suspended-particulate concentrations estimated by the diffusion model for the Detroit - Windsor area are given in Table 4-2; the particle background level of 40 ug/m^3 used was determined from historical National Air Sampling Network (NASN) data. Measurements made at "clean" sites during the study were added as background levels to all model estimates. The actual observed particulate concentrations provide comparisons by which to verify the model. Of the 34 particulate estimates made by the model, only three were in error by substantially more than a factor of two; however, for two of these three, observed data were not available for the entire study period. A regression

Table 4-2. OBSERVED AVERAGE PARTICULATE CONCENTRATIONS VERSUS MODEL ESTIMATES FOR DETROIT - WINDSOR AREA

Station number	Operating period	Number of observations	Arithmetic mean, $\mu g/m^3$	Model estimate, $\mu g/m^3$
201	12/67-11/68	114	110	198
202	12/67-11/68	116	133	241
203	12/67-11/68	99	183	290
204	3/68-11/68	84	137	195
205	12/67-11/68	93	140	176
206	12/67-7/68	67	129	141
207	12/67-11/68	109	101	138
209	12/67-11/68	102	91	144
211	3/68-11/68	88	76	113
212	3/68-11/68	95	79	176
215	5/68-11/68	65	97	117
217	4/68-11/68	87	77	79
220	4/68-11/68	86	120	284
400	3/68-11/68	72	107	189
401	12/67-11/68	110	71	153
402	12/67-11/68	100	111	195
403	12/67-11/68	199	96	192
404	12/67-11/68	103	136	200
406	12/67-11/68	197	152	297
407	12/67-11/68	92	136	234
409	12/67-11/68	176	103	163
411	12/67-11/68	108	85	159
412	12/67-11/68	214	69	93
414	12/67-11/68	203	127	226
415	12/67-11/68	108	115	172
416	12/67-11/68	117	85	116
417	12/67-11/68	104	73	91
418	12/67-11/68	110	78	77
419	12/67-11/68	91	92	135
422	12/67-11/68	110	105	214
423	12/67-11/68	92	71	90
425	12/67-11/68	110	68	79
426	12/67-11/68	86	93	91
427	12/67-11/68	82	46	56

analysis of estimated versus observed concentrations gave a correlation coefficient of 0.83. The best-fit line through these data, found by the least squares technique, was: observed data = 0.38 (model-estimated data) + 40 (Figure 4-7). The spatial distribution of observed and model-estimated particulate concentrations in the Detroit - Windsor area are given respectively in Figures 4-8 and 4-9. The contour lines for the estimated values have been drawn for levels equivalent to those of the observed levels; the best-fit equation was used to determine this equivalence. The locations and areas encompassed by the various concentration levels agree well. The only discrepancy is a rotation of the area of highest concentrations slightly to the west of where the observed data indicated it should be. The high correlation and the excellent agreement between the spatial distribution of observed and estimated concentrations indicate that considerable confidence can be placed in the use of the model for estimating accurately the impact of various source categories on air quality with respect to particles.

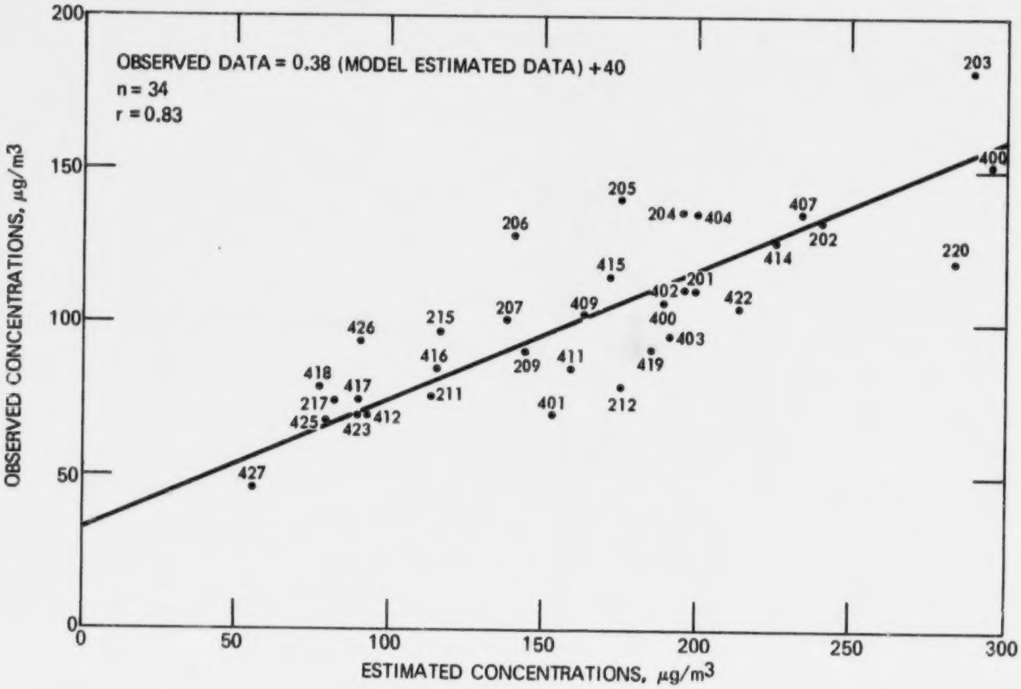


Figure 4-7. Observed versus estimated particulate concentrations for Detroit - Windsor area.

Continuous sulfur dioxide measurements were not sufficient to define adequately the spatial distribution of annual average concentrations in the Detroit - Windsor area. Data were available, however, from an extensive network of sulfation candles, which measure concentrations of sulfurous compounds as mg SO_3/100 cm^2-day. By comparing these data and all available SO_2 data for the IJC Study Area (180 station-months), it was found that, on the average, a sulfation rate of 1.0 mg SO_3/100 cm^2-day could be converted to parts per million of SO_2 by using a conversion factor of 0.022; for example, an annual average sulfation rate of 1.0 is equivalent to an average SO_2 concentration of 0.022 ppm.

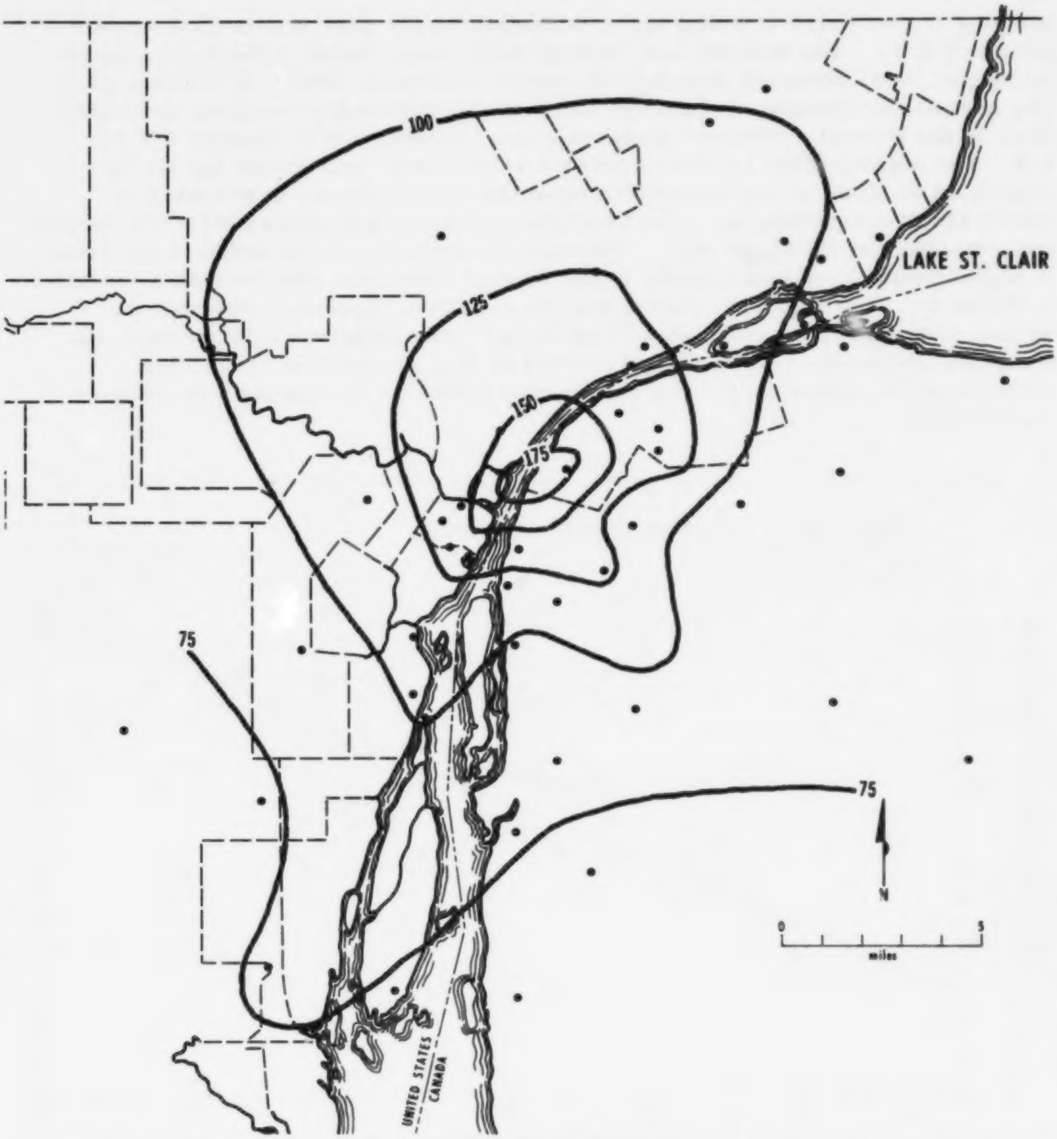


Figure 4-8. Spatial distribution of observed particulate concentrations ($\mu g/m^3$) for Detroit - Windsor area.

The conversion to SO_2 of the measured and model-estimated sulfation rates are given in Table 4-3. Of the 37 model estimates, two-thirds are within a factor of 2.5 of the converted sulfation observations; only four deviate by more than a factor of 3.

A regression analysis of estimated versus observed data gave a correlation coefficient of 0.81. The best-fit line through these data, found by the least squares techniques, was: observed data = 0.29 (model-estimated data) + 0.009 (Figure 4-10). The spatial distributions of SO_2 concentrations in the Detroit - Windsor Area are given respectively in Figures 4-11 and 4-12 for converted

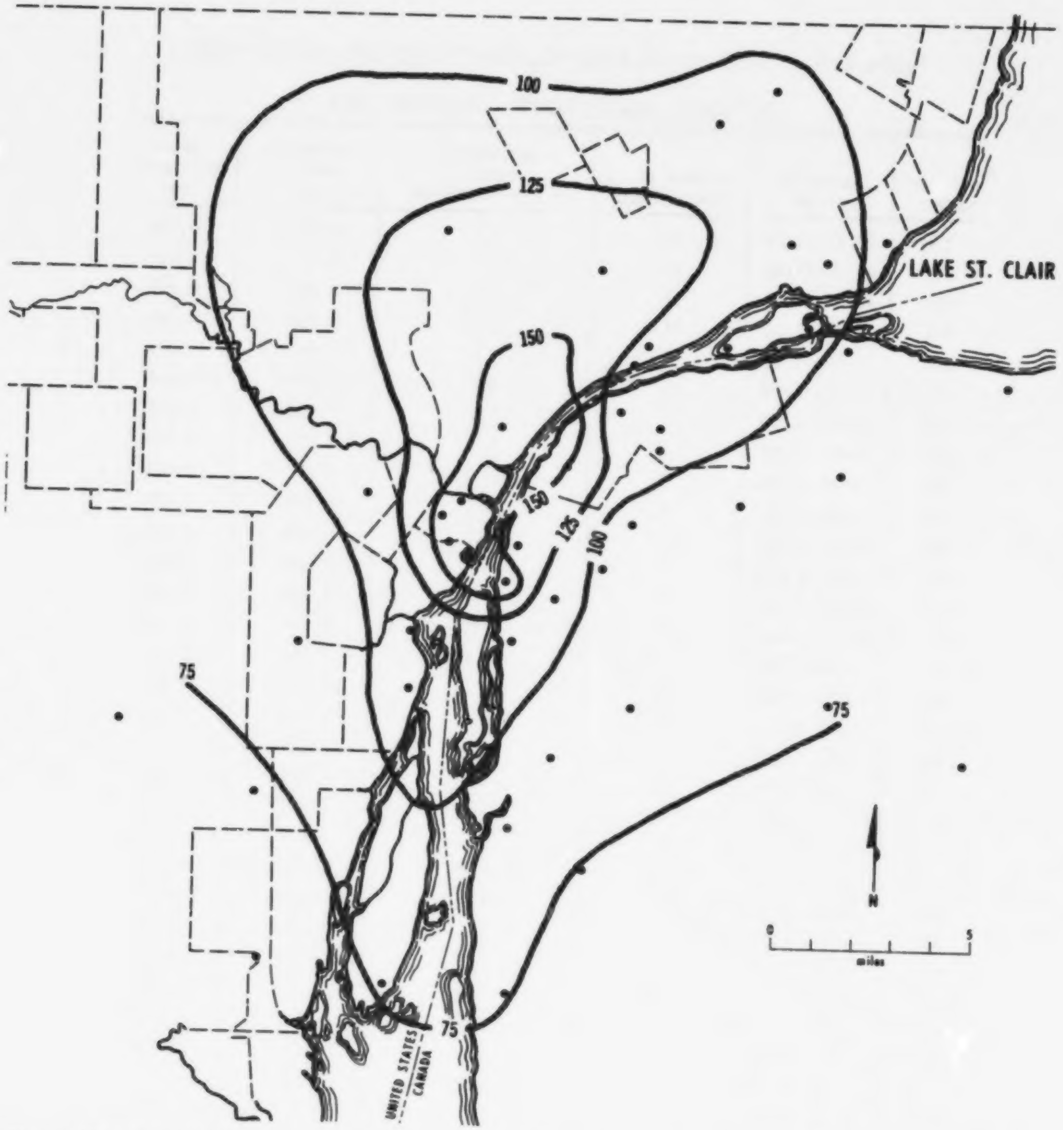


Figure 4-9. Spatial distribution of estimated particulate concentrations ($\mu g/m^3$) for Detroit - Windsor area.

sulfation-rate data and model-estimated data. Overall, the agreement is quite good. Although the patterns appear to be somewhat different, the only significant discrepancy is the westward displacement of the estimated maximum. The appearance of slightly lower observed concentrations through the center of the area is of no real consequence and is probably biased by an incomplete set of data from Station 212. Generally, the observed and estimated values agreed rather well, so that satisfactory confidence can be placed in model estimates of relative source impact.

Table 4-3. OBSERVED AVERAGE SO_2 CONCENTRATIONS VERSUS MODEL ESTIMATES FOR DETROIT - WINDSOR AREA

Station number	Operating period	Number of observations	Arithmetic mean, $\mu g\ SO_2/100cm^2$-day	Arithmetic mean, ppm	Model estimate, ppm
201	12/67-11/68	11	1.1	0.024	0.054
202	12/67-11/68	11	1.7	0.037	0.069
203	12/67-11/68	11	2.4	0.053	0.109
205	12/67-11/68	11	1.2	0.026	0.066
206	12/67-11/68	7	1.0	0.022	0.044
207	12/67-11/68	11	1.1	0.024	0.046
209	12/67-11/68	11	1.1	0.024	0.054
210	12/67-11/68	9	1.2	0.026	0.026
211	4/68-11/68	8	0.8	0.018	0.029
212	4/68-11/68	8	0.7	0.015	0.050
213	12/67-11/68	11	0.7	0.015	0.021
214	12/67-11/68	7	1.1	0.024	0.033
215	12/67-11/68	11	0.8	0.018	0.032
216	12/67-11/68	10	0.8	0.018	0.024
217	4/68-11/68	8	0.6	0.013	0.018
218	12/67-11/68	10	0.9	0.020	0.041
219	12/67-11/68	10	0.7	0.015	0.040
220	8/68-11/68	4	1.1	0.024	-[b]
400	6/68-11/68	6	1.6	0.035	0.076
401	12/67-11/68	11	1.0	0.022	0.058
402	12/67-11/68	11	1.2	0.027	0.079
403	12/67-11/68	10	1.4	0.031	0.080
404	12/67-11/68	11	1.7	0.037	0.084
406	12/67-11/68	11	2.1	0.046	0.106
407	12/67-11/68	11	1.9	0.042	0.088
409	12/67-11/68	11	1.1	0.024	0.045
411	12/67-11/68	11	1.2	0.027	0.034
412	12/67-11/68	10	1.0	0.022	0.024
413	2/68-11/68	9	0.9	0.020	0.052
414	12/67-11/68	12	1.2	0.027	0.095
415	12/67-11/68	11	1.2	0.027	0.060
416	12/67-11/68	11	0.9	0.020	0.031
417	12/67-11/68	12	0.7	0.015	0.024
418	12/67-11/68	11	0.6	0.013	0.019
419	12/67-11/68	12	0.8	0.018	0.072
422	12/67-11/68	11	1.0	0.022	0.085
423	12/67-11/68	12	0.6	0.013	0.020
425	12/67-11/68	12	0.5	0.011	0.016

[a] Derived from sulfation measurements.

[b] No model estimate was attempted.

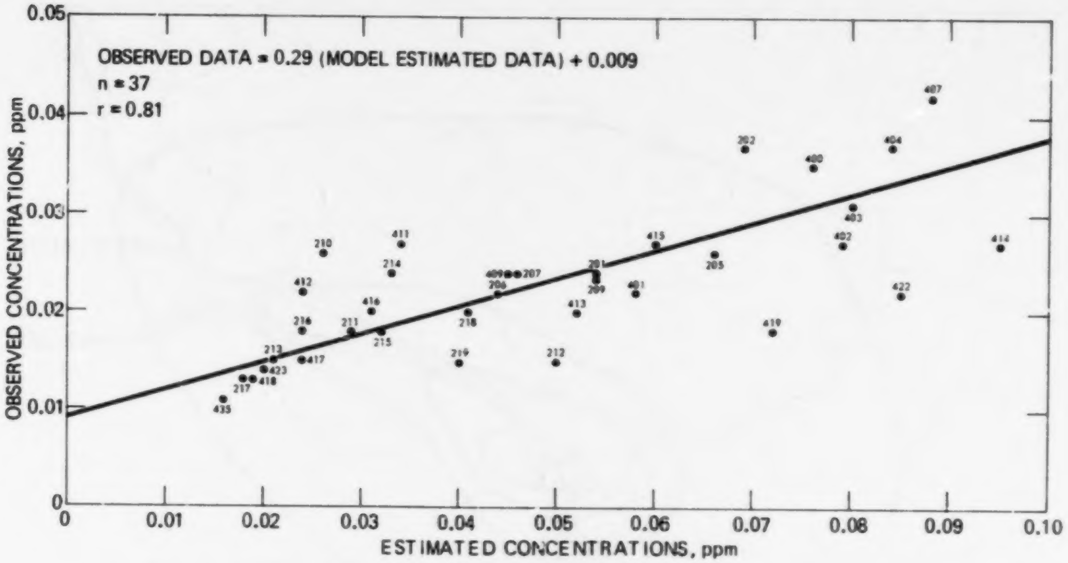


Figure 4-10. Observed versus estimated SO_2 concentrations for Detroit - Windsor area.

The suspended-particulate concentrations estimated by the diffusion model for the Port Huron-Sarnia River area are given in Table 4-4; a particle background level of 40 µg/m^3 was also used here. Of the 21 particulate estimates, all were well within a factor of 2 of the observed data. The regression analysis gave a correlation coefficient of 0.82 and a best-fit line of: observed data = 0.75 (model-estimated data) + 4 (Figure 4-13).

The spatial distribution of particulate concentrations for observed and the model-estimated data in the Port Huron - Sarnia area are given respectively in Figures 4-14 and 4-15. The size of the areas affected by observed concentrations greater than 75 µg/m^3 are greater than the model has estimated; however, the relative distributions of particulate concentrations are quite similar.

The spatial distributions of observed and estimated SO_2 concentrations for the Port Huron - Sarnia area (Figures 4-16 and 4-17), are similar, with the exception of the southern portion of the area. Here the very high observed value at Station 159 was not reflected in the model estimates (Figure 4-18). A power plant and an industrial plant are close to this site and their impact may not have been properly evaluated by the model.

A statistical comparison of the 29 SO_2 model estimates with converted sulfation measurements (Table 4-5) provides good agreement with the exception of Station 159; two-thirds of the model estimates are within a factor of 2.5 of the observed data. Analysis, when Station 159 was eliminated from consideration, gave a correlation coefficient of 0.82 and a best-fit line of: observed data = 0.23 (model-estimated data) + 0.009 (Figure 4-18).

Even with the erroneous estimates given by the model at one site, the overall agreement between the model estimates and observed data is thought to be sufficient for model use in evaluating the relative impact of SO_2 and particulate emissions from various source categories in the Port Huron - Sarnia area.

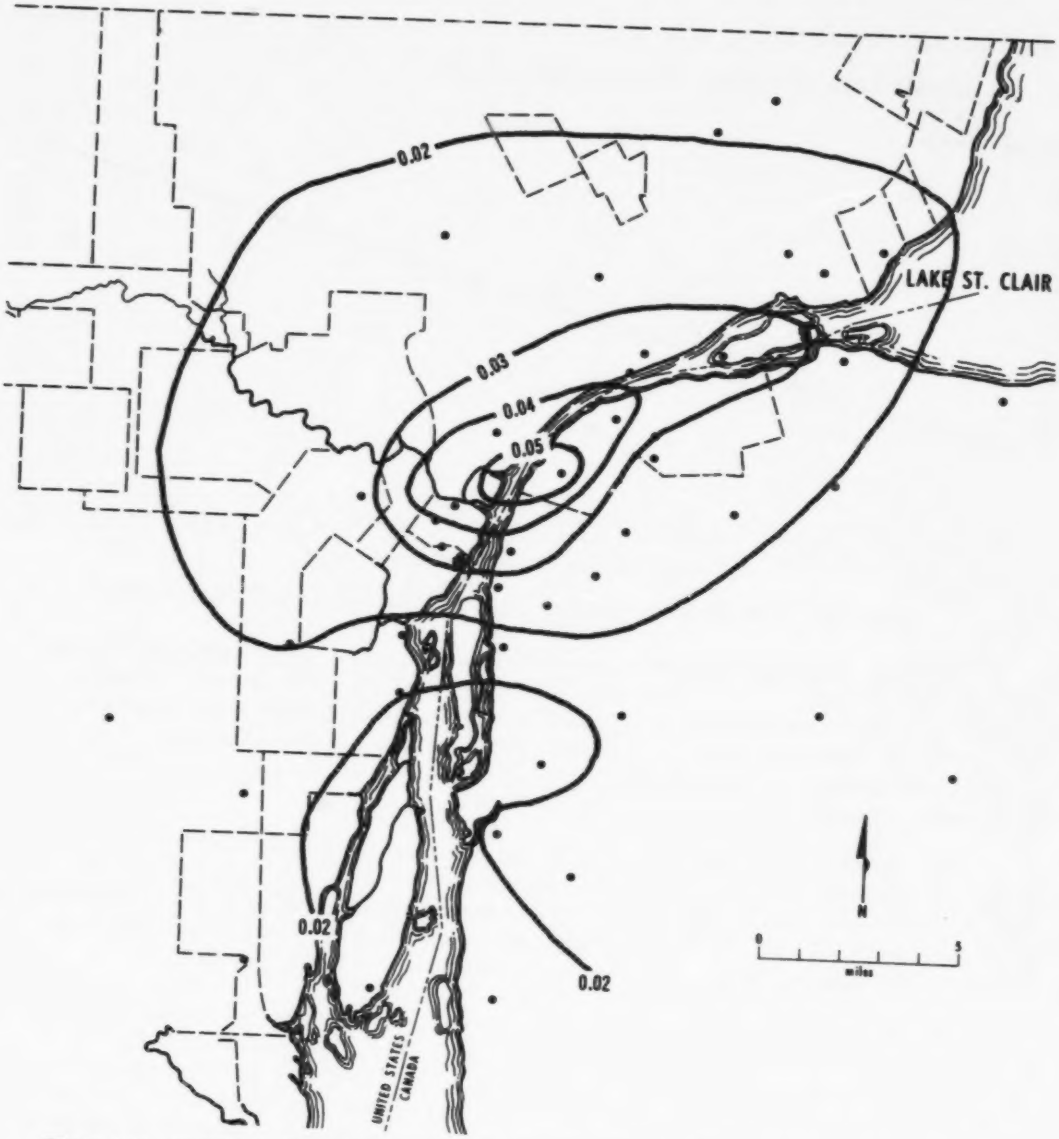


Figure 4-11. Spatial distribution of measured SO_2 concentrations (ppm) for Detroit - Windsor area.

4.2.2 Estimates of Pollutant Concentrations Due to Transboundary Flow

The observed air quality, meteorological data, emission information, and the dispersion model discussed in the previous section were used to evaluate the transboundary flow of air pollution. Sources in Canada and the United States were considered separately so that the contribution of one country to the pollution of the other country could be estimated. The effects of point sources and area sources were considered separately.

The ground-level concentrations shown in Figures 4-19 to 4-42 were developed by relating observed air quality to dispersion model estimates of the percentage

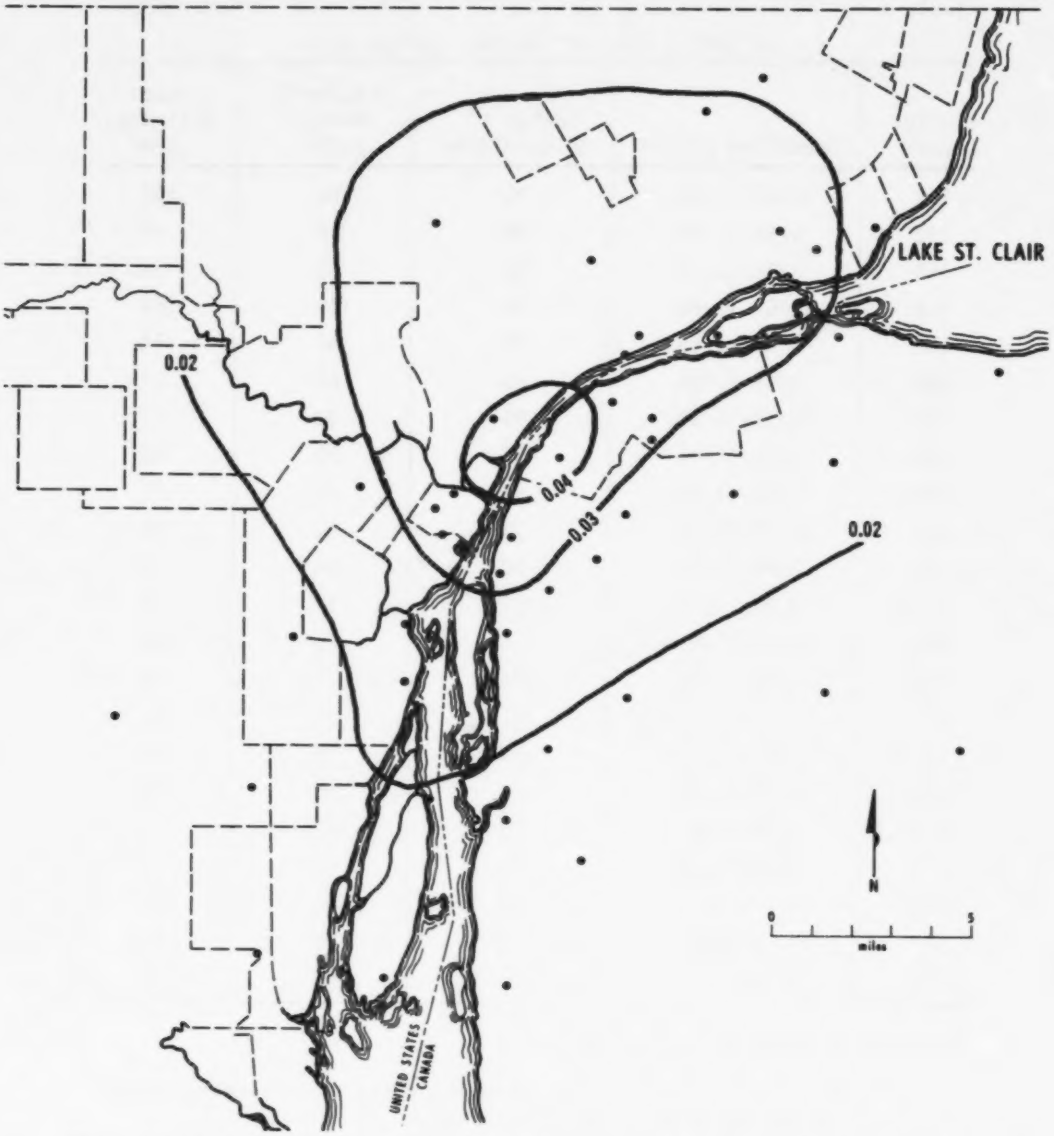


Figure 4-12. Spatial distribution of estimated SO_2 concentrations (ppm) for Detroit - Windsor area.

contribution of particular categories of sources to ground-level concentrations. A source category might be classified by country, type (point or area), and by pollutant. At a given receptor, observed concentration attributed to a particular source category was determined as follows.

For particles: $$P_E = P_D \; (P_M - 40) \qquad (1)$$

P_E = estimated portion of the observed concentration of particles in $\mu g/m^3$, at a given receptor attributed to the given source category;

P_D = that portion of the total concentration of particles, in $\mu g/m^3$, at a

Table 4-4. OBSERVED AVERAGE PARTICULATE CONCENTRATIONS VERSUS MODEL ESTIMATES FOR PORT HURON - SARNIA AREA

Station number	Operating period	Number of observations	Arithmetic mean, μg/m³	Model estimate, μg/m³
151	12/67-11/68	96	103	137
152	9/68-11/68	20	66	-[a]
153	3/68/11-68	84	58	71
154	12/67-11/68	95	119	109
155	4/68-11/68	79	101	114
156	3/68-11/68	83	64	77
158	12/67-11/68	95	92	117
159	3/68-11/68	87	69	82
160	12/67-11/68	96	70	95
161	12/67-11/68	87	85	95
163	3/68-11/68	80	64	78
301	12/67-11/68	209	91	128
303	12/67-11/68	221	76	108
303	12/67-11/68	224	71	85
307	12/67-11/68	221	64	82
310	12/67-11-68	188	95	136
314	12/67-11/68	89	65	89
315	12/67-6/68	50	53	78
316	12/67-11/68	102	52	78
317	12/67-6/68	36	66	77
318	12/67-6/68	52	48	78
319	12/67-11/68	96	53	79

[a] No model estimate was attempted.

given receptor contributed by the given source category as estimated by the dispersion model;

$P_M - 40$ = observed total concentration of particles, in $\mu g/m^3$, at a given receptor, less assumed background concentration.

For sulfur dioxide: $S_E = S_D - S_M$ (2)

S_E = estimated portion of the total observed concentration of SO_2, in ppm, at a given receptor attributed to the given source category;

S_D = that portion of the total concentration of SO_2, in ppm, at a given receptor contributed by the given source category as estimated by the dispersion model;

S_M = observed concentration of SO_2, in ppm, at a given receptor.

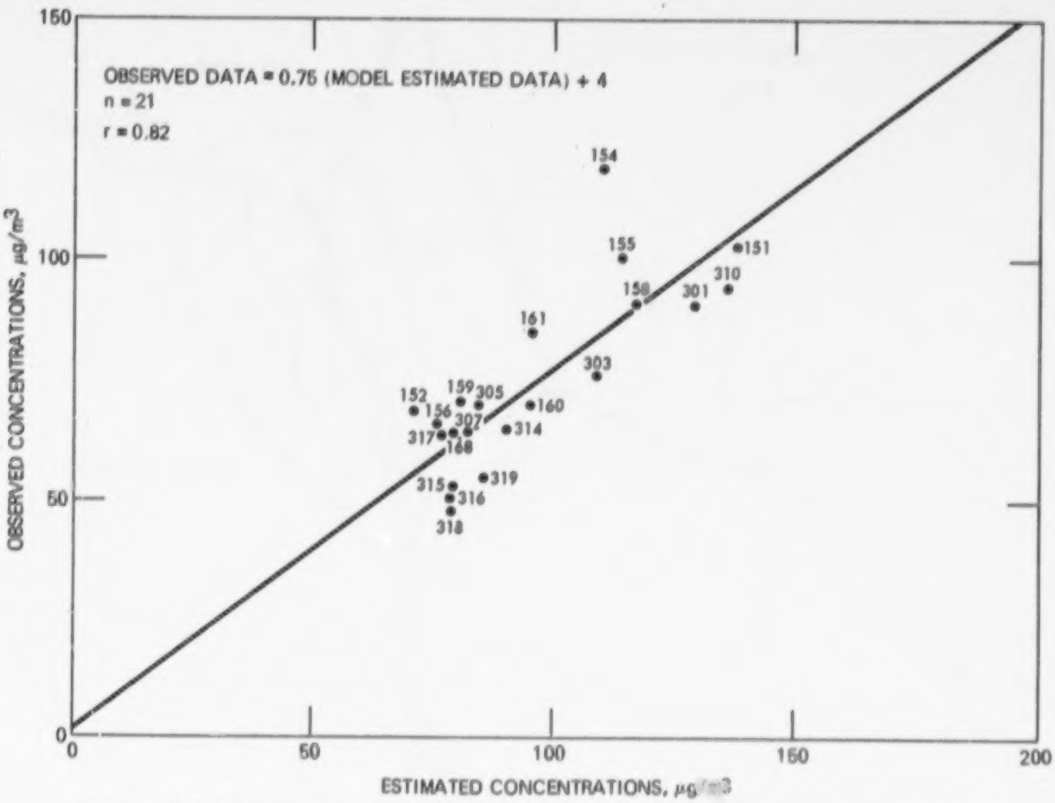


Figure 4-13. Observed versus estimated particulate concentrations for Port Huron - Sarnia area.

It should be noted that dispersion model estimates of concentrations never directly entered the estimates reflected in P_E and S_E. Only the ratio of calculations for a given source category to calculations for all sources was used. For this reason the estimates, P_E and S_E, can be treated as accurate well within a factor of 2, assuming, of course, that the observed air quality data are reliable.

The estimated contributions of U.S. point and area sources to the annual average SO_2 concentrations in the Windsor, Ontario, area are shown in Figures 4-19 to 4-21. The pattern of U.S. contribution from point sources to the Canadian SO_2 pollution shown in Figure 4-20 reflects the industrial activity in the southern portion of Detroit. United States point source contributions range from 0.030 ppm to 0.004 ppm. Area sources in the U.S. produce a smaller range of contributions to Canadian SO_2 pollution (Figure 4-21). Contributions range from 0.013 ppm to 0.006 ppm. As can be seen in Figure 4-19, the sum of estimated contributions from the U.S. sources reaches values as high as 0.043 ppm (Station 203)—well above the acceptable annual average value of 0.02 ppm set by the Ontario standard.

Figures 4-22 to 4-24 show the estimated contribution of Canadian point and area sources to annual average SO_2 pollution concentrations in the Detroit area. The Canadian contributions are insignificant except those from area sources affecting Belle Isle and the Grosse Point area to the northeast.

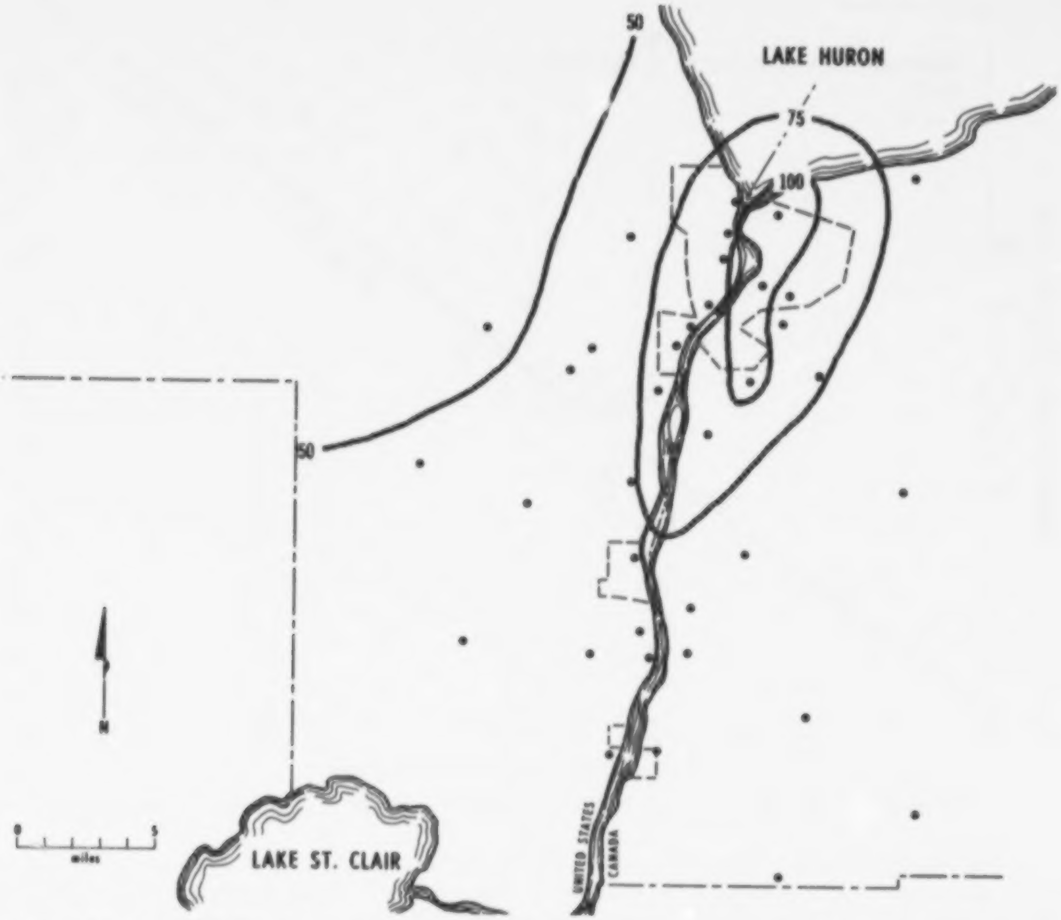


Figure 4-14. Spatial distribution of measured particulate concentrations ($\mu g/m^3$) for Port Huron-Sarnia area.

The estimated contributions of U.S. area and point sources to the annual average concentrations of particulates in the Windsor area are shown in Figures 4-25 to 4-27. It appears from these patterns that U.S. sources contribute at least the equivalent of the entire annual average particulate concentration loadings allowed under Ontario regulations (60 $\mu g/m^3$) for a large portion of the Windsor area. For some regions, particulate pollution from the U.S. may exceed the Ontario regulations by more than 50 percent. The U.S. point sources produce large maximum particulate concentrations on an annual average basis, but the area affected is small and the gradient away from the area of maximum is large. In general, although different regions are affected, the areas enclosed by lines of equal concentration, for values less than 50 $\mu g/m^3$, are approximately the same for point area sources.

The portion of the Detroit area affected by Canadian area and point sources of particulates are Belle Isle and the mainland area in the immediate vicinity. As

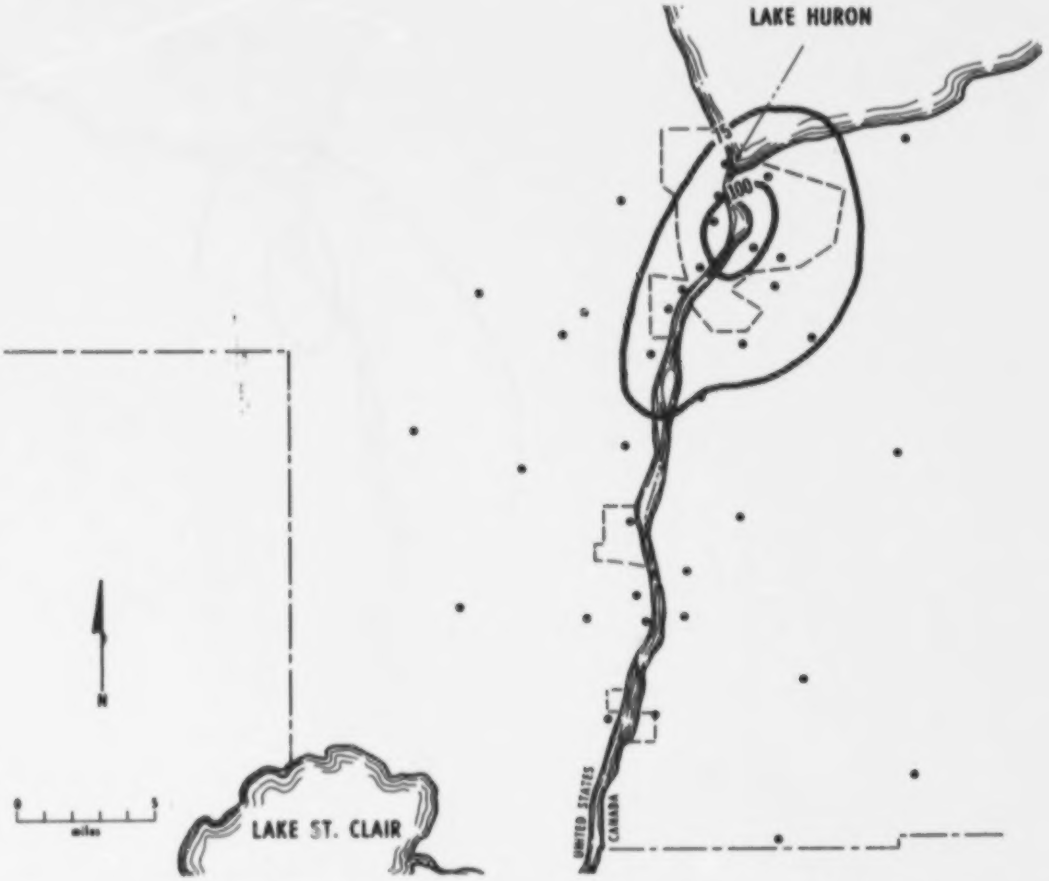


Figure 4-15. Spatial distribution of estimated particulate concentrations (µg/m3) for Port Huron - Sarnia area.

shown by the concentration patterns of Figures 4-28 to 4-30, the maximum contributions from Canada to the Detroit area average annual particulate concentrations appear to be well below the proposed Michigan values used as standards in this study.

The estimated SO_2 concentrations caused by the U.S. point and area sources over the Canadian portion of the Port Huron - Sarnia area are shown in Figures 4-31 to 4-33. Throughout the Canadian area opposite and south of St. Clair, Michigan, SO_2 from U.S. sources appears to exceed the concentration limits set by the Ontario standards. Outside this seriously affected region, the U.S. contributions may amount to approximately half of the limiting concentration value of the standards.

Canadian point and area sources (Figures 4-34 to 4-36) are estimated to produce annual average SO_2 concentrations in the eastern portion of the city of Port Huron that equal or closely approach the Ontario standards. These values, however, are well below the proposed Michigan standards for SO_2. Elsewhere in the U.S. portion of the area, Canadian contributions to SO_2 pollution can be considered insignificant.

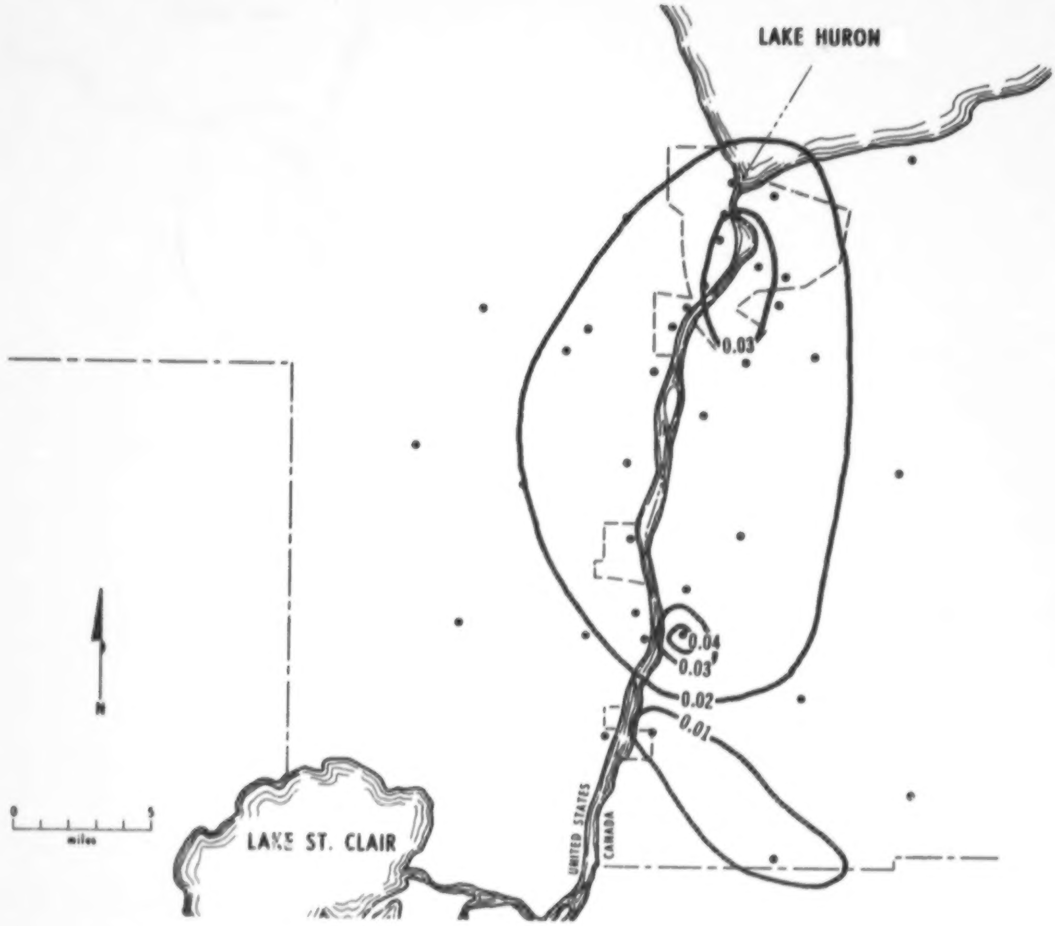


Figure 4-16. Spatial distribution of measured SO_2 concentrations (ppm) for Port Huron-Sarnia area.

Over the industrial area south of Sarnia, Ontario, U.S. point and area sources are estimated to contribute, on an annual average basis, more than 35 $\mu g/m^3$ of suspended particulates. The patterns of the U.S. contributions from point and area sources are shown in Figures 4-37 to 4-39. In general, throughout the region north of Sarnia, Ontario, and within about 6 miles of the St. Clair River, U.S. sources appear to contribute particulate pollution amounting to approximately one-half of the total concentration allowed under the Ontario standards. The southeastern portion of Port Huron, Michigan, may be seriously affected by particulate pollution originating from Canadian point and area sources (Figures 4-40 to 4-42). This section of Port Huron receives, on an average basis, particulates amounting to approximately one-third of the concentration allowed under the proposed Michigan standards. Outside this section, however, the Canadian contributions to the U.S. particulate pollution are rather insignificant.

4.3 TRANSBOUNDARY FLUX MEASUREMENTS

Measurements of SO_2 and suspended particulate concentrations were made during 13 airplane flights above sections of the international border along the

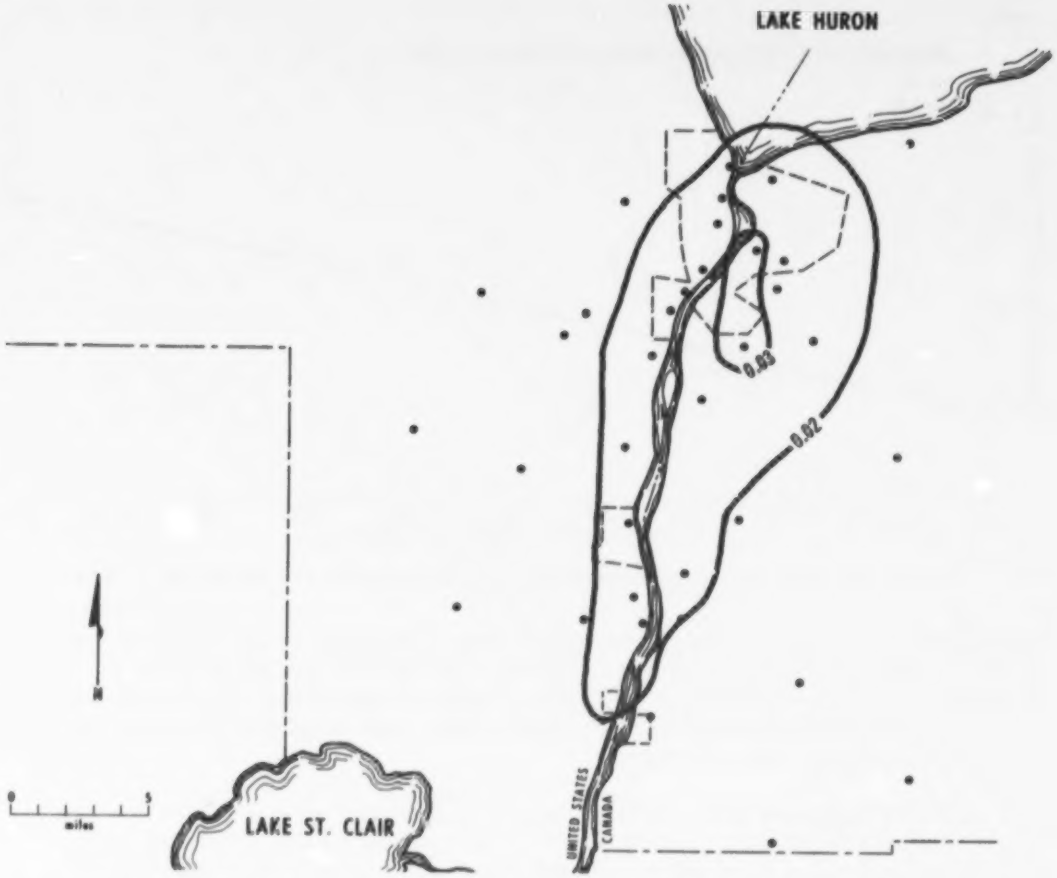


Figure 4-17. Spatial distribution of estimated SO_2 concentrations (ppm) for Port Huron-Sarnia area.

Detroit and St. Clair Rivers. On the basis of these measurements and concurrent meteorological data, estimates were made of the amount of each of these pollutants flowing from one country to another. Results of quantitative estimates of transboundary transport from pollutant measurements made above the Detroit River on May 22, 1968, and above the St. Clair River on May 24, 1968, are given in Table 4-6. Figure 4-43 shows the flight paths and identifies the segments of the border used in the computations; Figures 4-44 through 4-47 show the actual pollutant measurements made at successive levels above the boundary. An instrument-equipped Cessna 336 aircraft operated under contract by Washington State University[2] was used to obtain the measurements. Measured concentrations of SO_2 and concentrations of particulate matter approximated from a relationship[3] to the measured light scatter coefficient values were used to compute the flux results according to the scheme shown in Figure 4-48.

On May 22, the winds were from the west, transporting pollution from the Detroit area into Canada. On the 24th, however, an easterly component of the wind carried the pollutants from Canada to the U. S.

The flux of pollutants indicated by the values in Table 4-6 appears consistent with the known sources in the Detroit and Sarnia areas except in the case of the

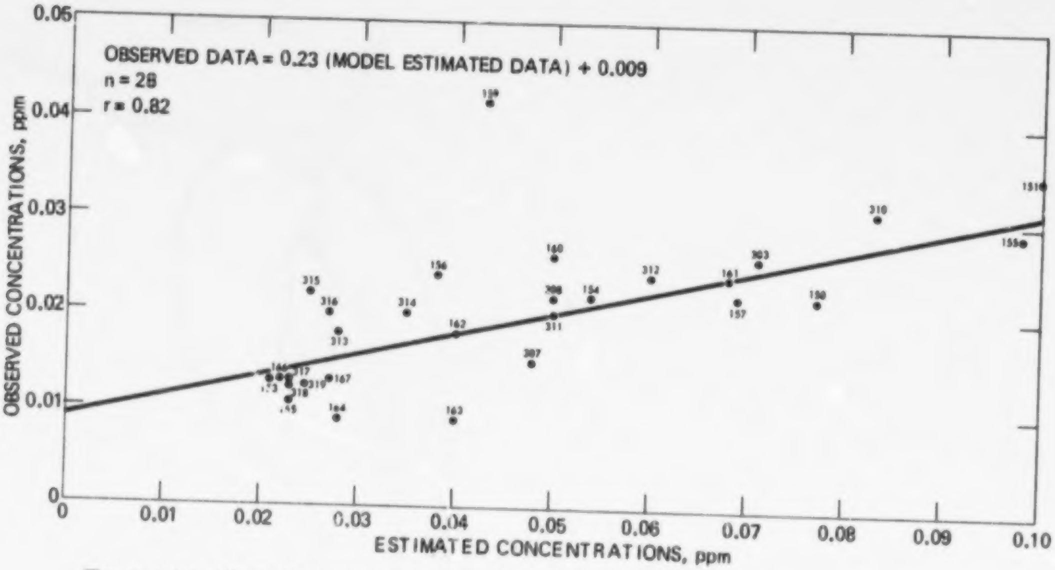


Figure 4-18. Observed versus estimated SO_2 concentrations for Port Huron - Sarnia area.

particulate transport across the St. Clair River (May 24). The flux of 14 x 10^3 g/sec, more than three times as large as the flux across the Detroit River, resulted from a combination of a relatively high background concentration of particulates in the air mass over the region and a high wind speed that transported large volumes of air per unit time.

These measurements illustrate that transboundary flow of pollutants can occur in sizeable quantities from either country to the other, depending on the wind direction. Also, the actual amount of pollution transported is a result, not only of the local sources, but of background concentrations as well, particularly in the case of suspended particulates.

4.4 CASE STUDIES OF MEASURED HIGH POLLUTANT CONCENTRATIONS

For the purpose of proving the occurrence of transboundary flow of pollution, an analysis was made of the wind directions which accompanied SO_2 and high values of the soiling index at Stations 310, 156, 203, and 404. The stations selected for this analysis, two on the Canadian side and two on the U. S. side of the boundary, are at locations where meteorological data could readily indicate whether the high concentrations occurred because of a transboundary flow of pollutants.

The wind directions were determined for the periods that hourly average concentrations of SO_2 exceeded 0.3 ppm or the soiling index (2-hour values) exceeded 2.0 Coh/1,000 lineal feet. Average SO_2 concentrations greater than 0.3 ppm for several hours are known to have caused adverse effects on some vegetation. Soiling index measurements, obtained by a tape sampler in units of Coh/1,000 lineal feet are an indirect method of measuring the fine suspended particulates in the atmosphere. The correlation between the soiling index readings and the particulate loading as obtained by a high-volume sampler differs from place to

Table 4-5. OBSERVED AVERAGE SO_2 CONCENTRATIONS[a] VERSUS MODEL ESTIMATES FOR PORT HURON - SARNIA AREA

Station number	Operating period	Number of observations	Arithmetic mean, mg SO_3/100cm^2-day	Arithmetic mean, ppm	Model estimate, ppm
151	12/67-11/68	11	1.6	0.035	0.100
152	12/67-11/68	5	1.4	0.031	–[b]
153	12/67-11-68	11	0.6	0.013	0.021
154	12/67-11/68	11	1.0	0.022	0.054
155	12/67-11/68	11	1.3	0.029	0.098
156	12/67-11/68	11	1.1	0.024	0.038
157	12/67-11/68	11	1.0	0.022	0.069
158	12/67-11/68	11	1.0	0.022	0.077
159	12/67-11/68	11	1.9	0.042	0.043
160	12/67-11/68	11	1.2	0.026	0.050
161	12/67-11/68	11	1.1	0.024	0.068
162	12/67-11/68	11	0.8	0.018	0.040
163	3/68-11/68	8	0.4	0.009	0.040
164	3/68-11/68	8	0.4	0.009	0.028
165	3/68-11/68	8	0.5	0.011	0.023
166	3/68-11/68	8	0.6	0.013	0.022
167	3/68-11/68	8	0.6	0.013	0.027
170	4/68-11/68	3	0.9	0.020	–[b]
303	12/67-11/68	11	1.2	0.026	0.071
307	12/67-11/68	11	0.7	0.015	0.048
308	12/67-11/68	11	1.0	0.022	0.050
310	12/67-11/68	11	1.4	0.031	0.083
311	12/67-11/68	11	0.9	0.020	0.050
312	12/67-11/68	11	1.1	0.024	0.060
313	12/67-11/68	11	0.8	0.018	0.028
314	12/67-11/68	11	0.9	0.020	0.035
315	12/67-11/68	11	0.7	0.022	0.025
316	12/67-11/68	11	0.8	0.020	0.027
317	12/67-11/68	11	0.6	0.013	0.023
318	12/67-11/68	10	0.6	0.013	0.022
319	12/67-11/68	10	0.6	0.013	0.023

[a] Derived from sulfation measurements.

[b] No model estimate was attempted.

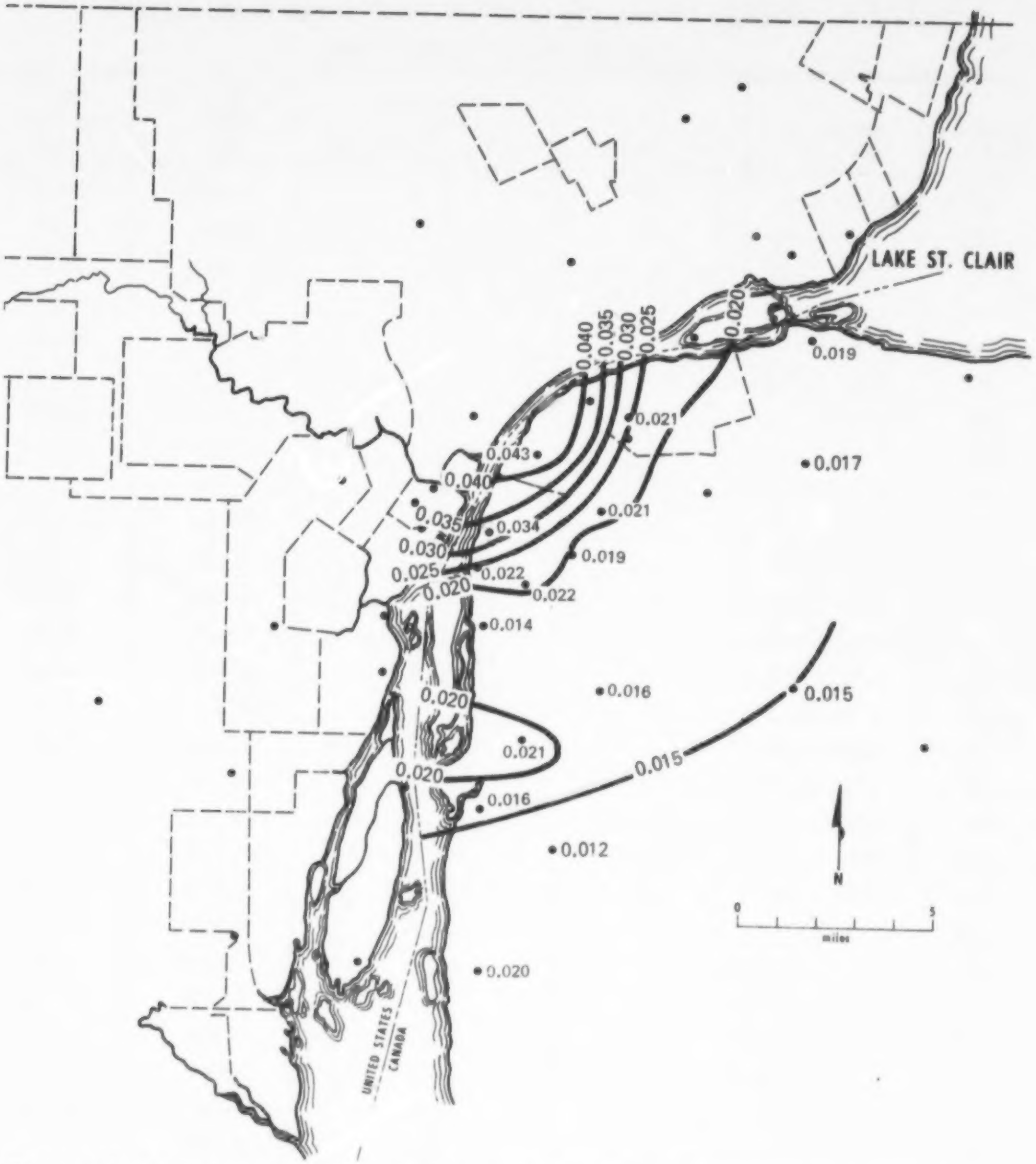

LAKE ST. CLAIR
0.040
0.035
0.030
0.025
0.020
0.019
0.021
0.043
0.040
0.017
0.035
0.034
0.021
0.030
0.019
0.025
0.022
0.020
0.022
0.014
0.016
0.020
0.015
0.021
0.015
0.020
0.016
0.012
N
0
5
miles
0.020
UNITED STATES
CANADA

Figure 4-19. Estimated contribution of U. S. sources to annual average concentrations of SO_2 (ppm) in Windsor area.

place depending on the characteristics of the particulates (color, particle size, etc.) present in the atmosphere. The more direct measurements of suspended particulates, that is, by means of high-volume samplers, were not used for this analysis as such readings are 24-hour values and could only be exactly related to simultaneous wind directions when the latter were constant for the full 24-hour period. Such occurrences are few in number. Studies have indicated that a soiling index exceeding 2.0 Coh/1,000 lineal feet would indicate a suspended particulate loading which may have adverse effects.

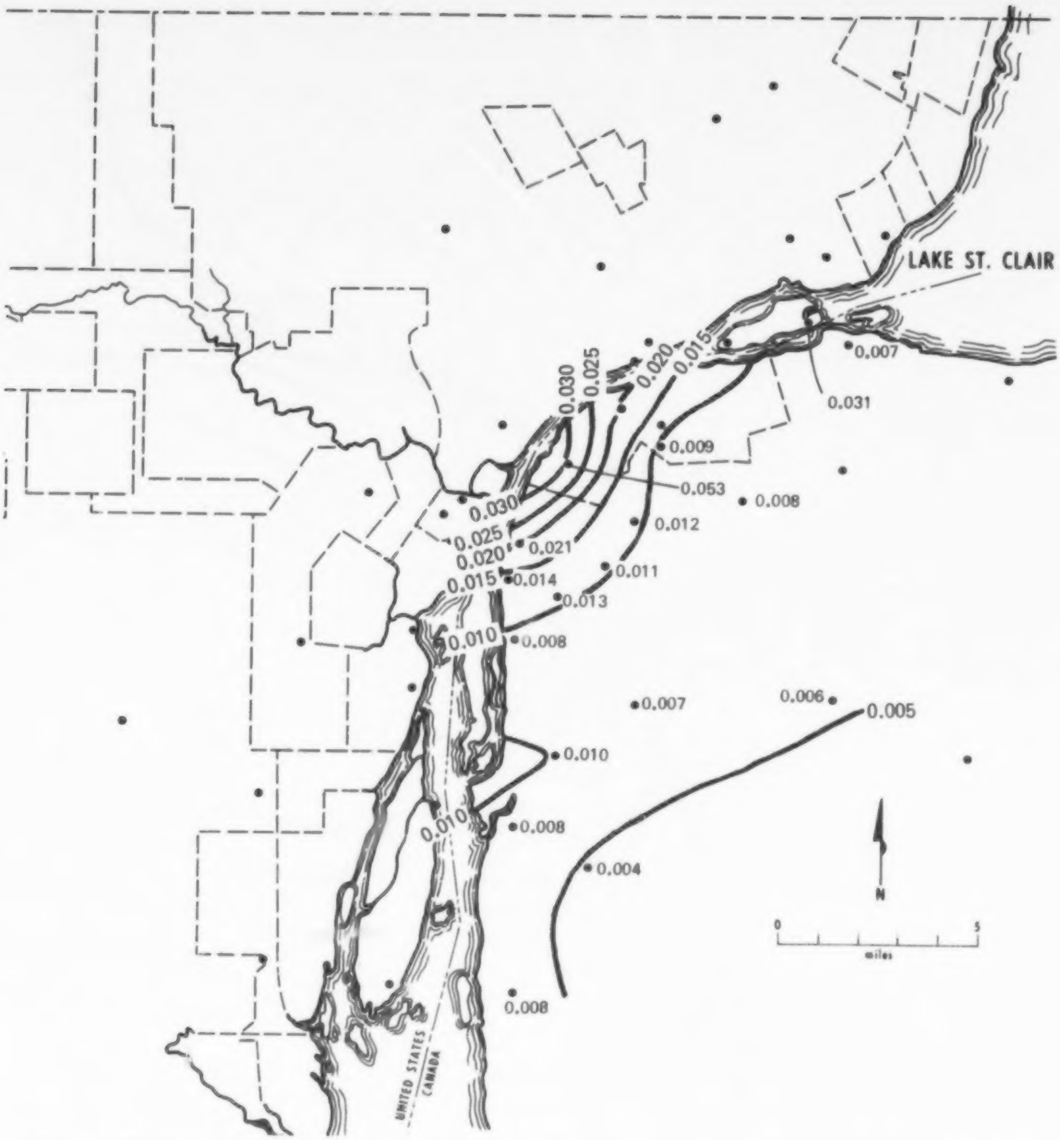

LAKE ST. CLAIR
0.030
0.025
0.020
0.015
0.007
0.031
0.009
0.053
0.008
0.030
0.012
0.025
0.021
0.020
0.015
0.014
0.011
0.013
0.010
0.008
0.006
0.005
0.007
0.010
0.010
0.008
0.004
N
0
5
miles
0.008
UNITED STATES
CANADA

Figure 4-20. Estimated contribution of U. S. point sources to annual average concentrations of SO_2 (ppm) in the Windsor area.

Table 4-7 gives the number of hours that winds were reported in the indicated direction during periods of high concentrations of SO_2 or high levels of the soiling index.

4.4.1 Case No. 1

Station 310 in Port Huron, Michigan, reported 2-hour average soiling indices exceeding 2.0 Coh/1,000 lineal feet with the wind directions from the sector 140

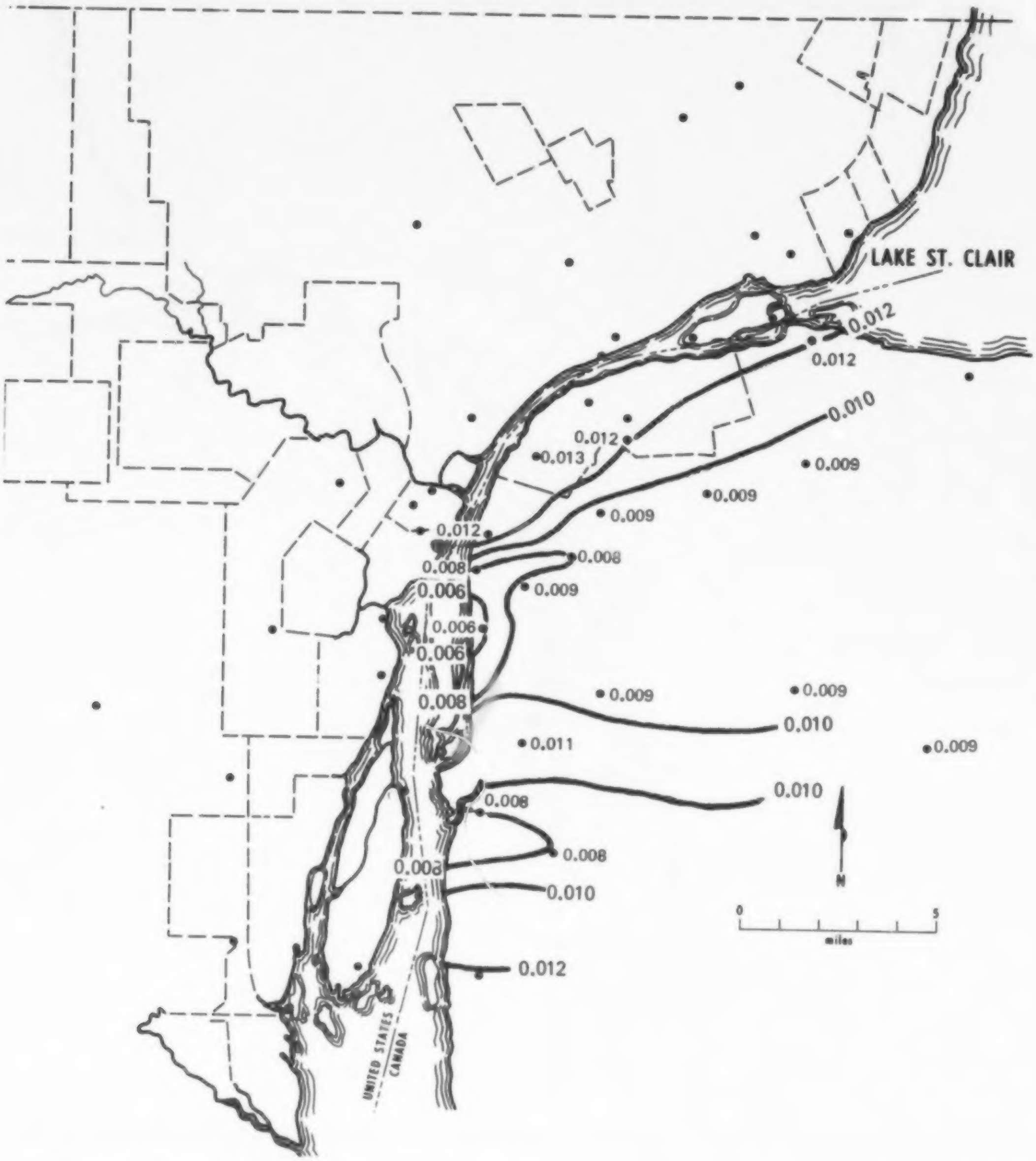

LAKE ST. CLAIR
0.012
0.012
0.010
0.012
0.013
0.009
0.009
0.009
0.012
0.008
0.008
0.006
0.009
0.006
0.006
0.008
0.009
0.009
0.010
0.011
0.009
0.010
0.008
0.008
0.008
0.010
0.012
N
0
5
miles
UNITED STATES
CANADA

Figure 4-21. Estimated contribution of U. S. area sources to annual average concentrations of SO_2 (ppm) in Windsor area.

to 200 degrees, the predominance of higher values occurring during a wind direction of 160 degrees. Winds from this direction would transport pollution from Canadian sources south of Sarnia across the boundary to the station in Port Huron.

4.4.2 Case No. 2

Station 156 located in Ontario, south of Sarnia, reported hourly average concentrations of SO_2 exceeding 0.3 ppm most frequently when the winds were

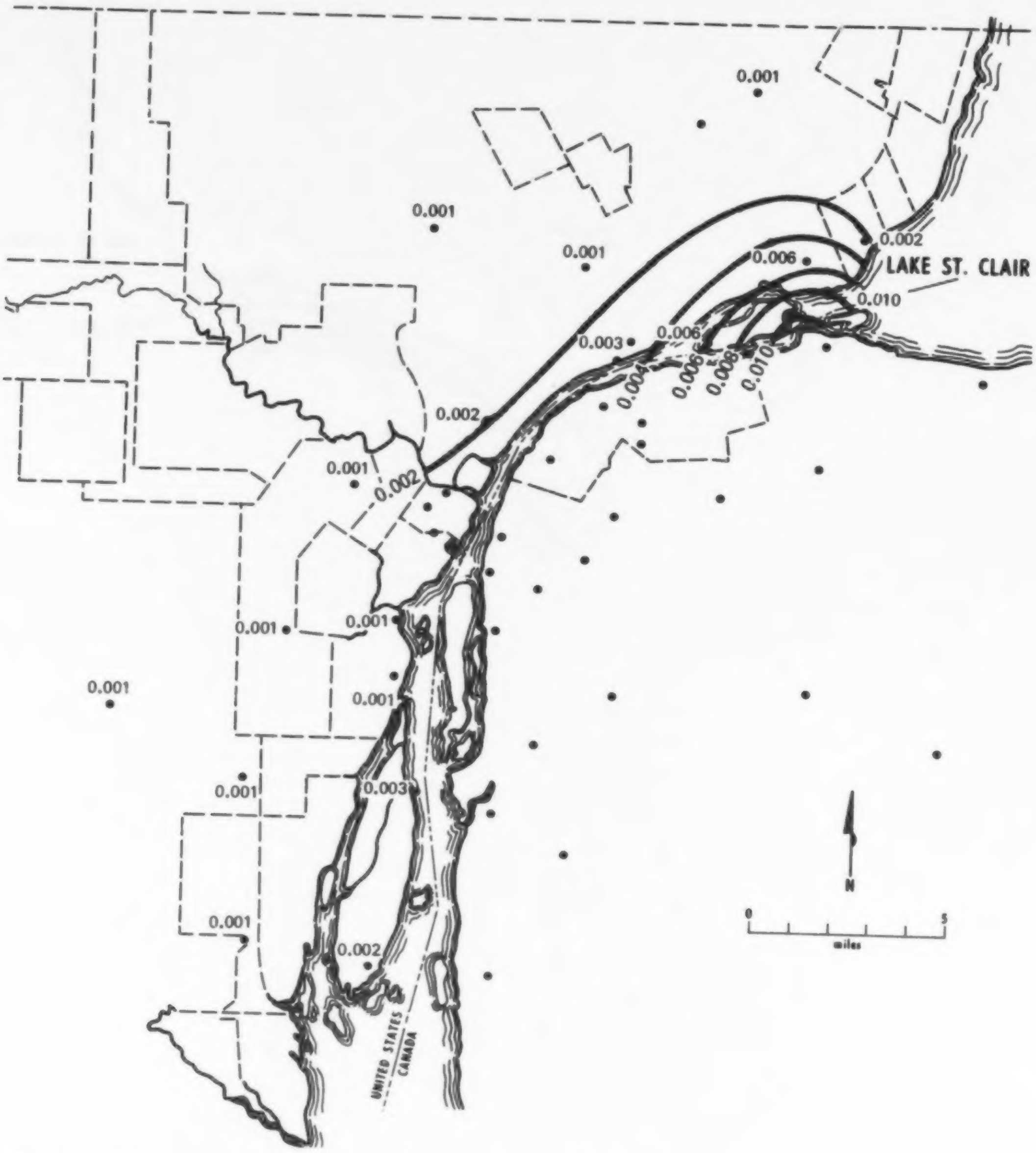

0.001
0.001
0.001
0.002
0.006
LAKE ST. CLAIR
0.010
0.003
0.006
0.004
0.006
0.008
0.010
0.002
0.001
0.002
0.001
0.001
0.001
0.001
0.001
0.003
0.001
0.002
UNITED STATES
CANADA
N
0
5
miles

Figure 4-22. Estimated contribution of Canadian sources to annual average concentration of SO_2 (ppm) in Detroit area.

from the direction of 200 degrees. Although Station 156 is located 3 to 4 miles from the boundary, the likely source of the SO_2 reaching this station with this wind direction is the generating station located on the U.S. side of the boundary. No significant Canadian sources were located between the sampling station and the boundary.

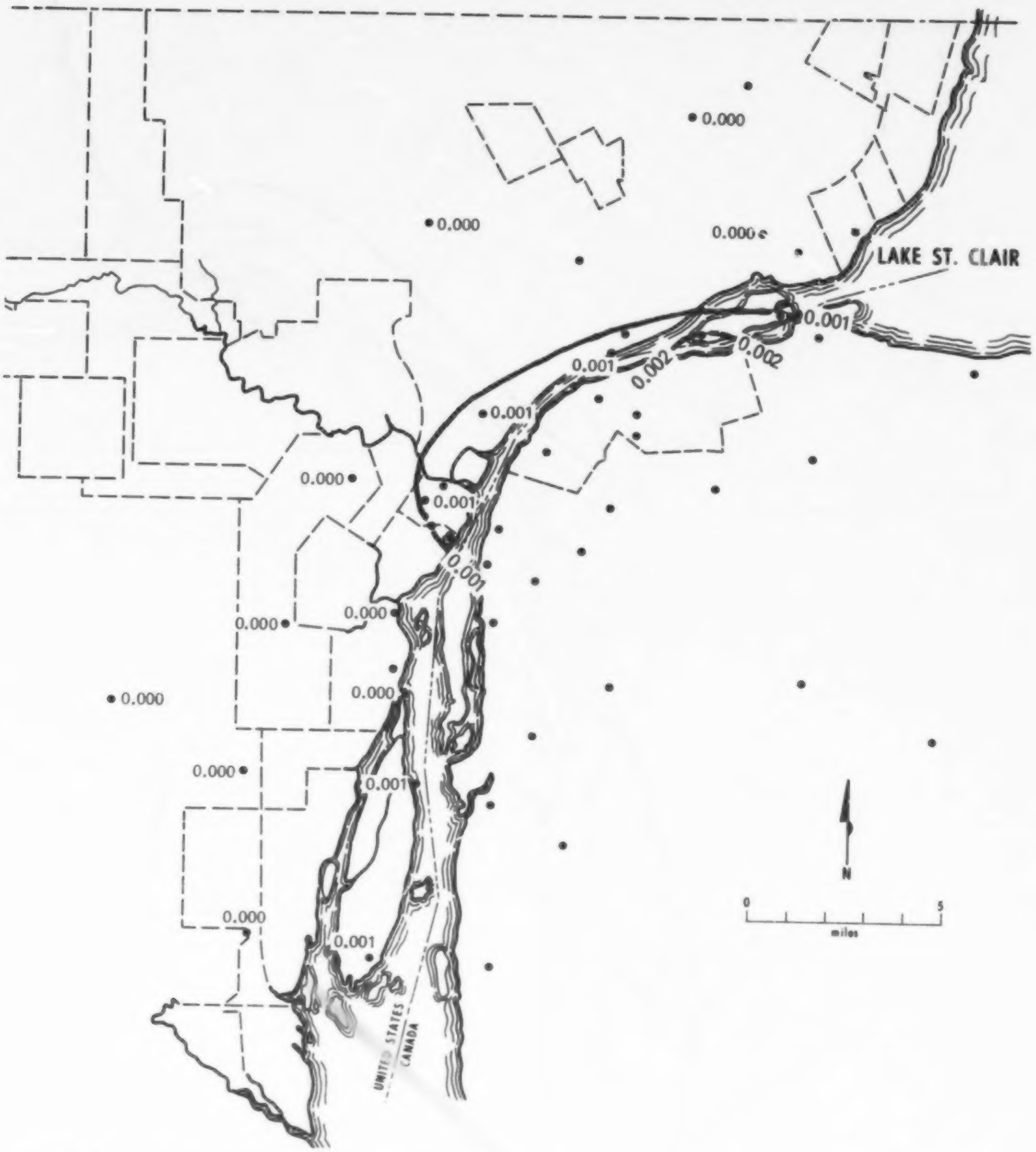

0.000
0.000
0.000
LAKE ST. CLAIR
0.001
0.001
0.002
0.002
0.001
0.000
0.001
0.001
0.000
0.000
0.000
0.000
0.000
0.001
0.000
0.001
UNITED STATES
CANADA
N
0
5
miles

Figure 4-23. Estimated contribution of Canadian point sources to annual average concentrations of SO_2 (ppm) in Detroit area.

4.4.3 Case No. 3

Station 203 in Windsor, Ontario, reported soiling indices exceeding 2.0 Coh/1,000 lineal feet most frequently when the wind was from the westerly direction, 260 to 280 degrees. This wind direction would carry pollutants to this station across the boundary from sources in Detroit.

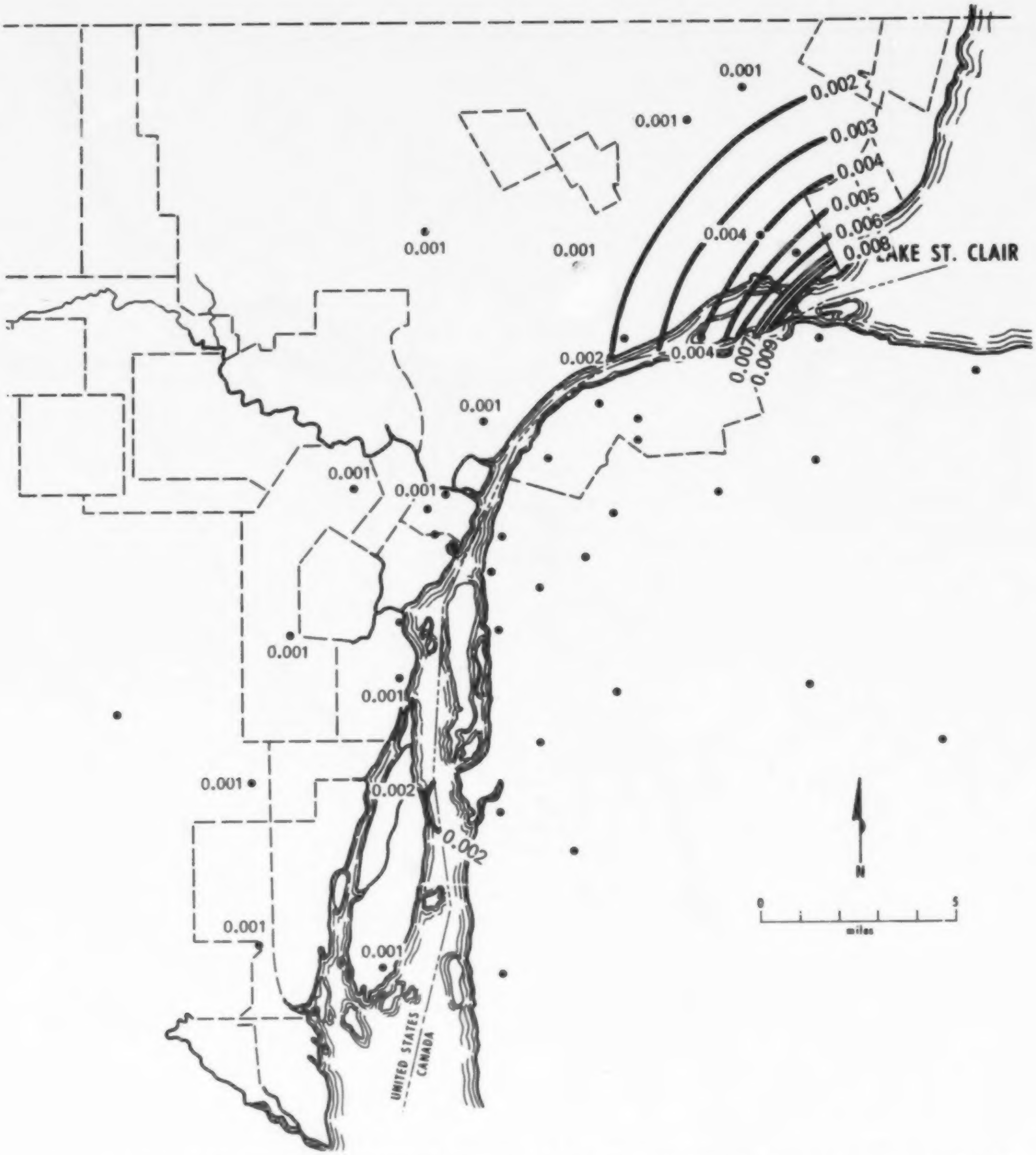

0.001
0.001
0.002
0.003
0.004
0.005
0.006
0.008
LAKE ST. CLAIR
0.004
0.001
0.001
0.002
0.004
0.007
0.009
0.001
0.001
0.001
0.001
0.001
0.001
0.002
0.002
0.001
0.001
UNITED STATES
CANADA
N
0
5
miles

Figure 4-24. Estimated contribution of Canadian area sources to annual average concentration of SO_2 (ppm) in Detroit area.

4.4.4 Case No. 4

Station 404 in Detroit reported concentrations of SO_2 exceeding 0.3 ppm most frequently when winds were from the direction of 200 to 220 degrees. The most likely sources of this pollutant, with winds in these directions, are on the U.S. side of the boundary. Pollutants would cross into Canada, passing over a portion of Windsor, and then would cross the boundary again to reach Station 404

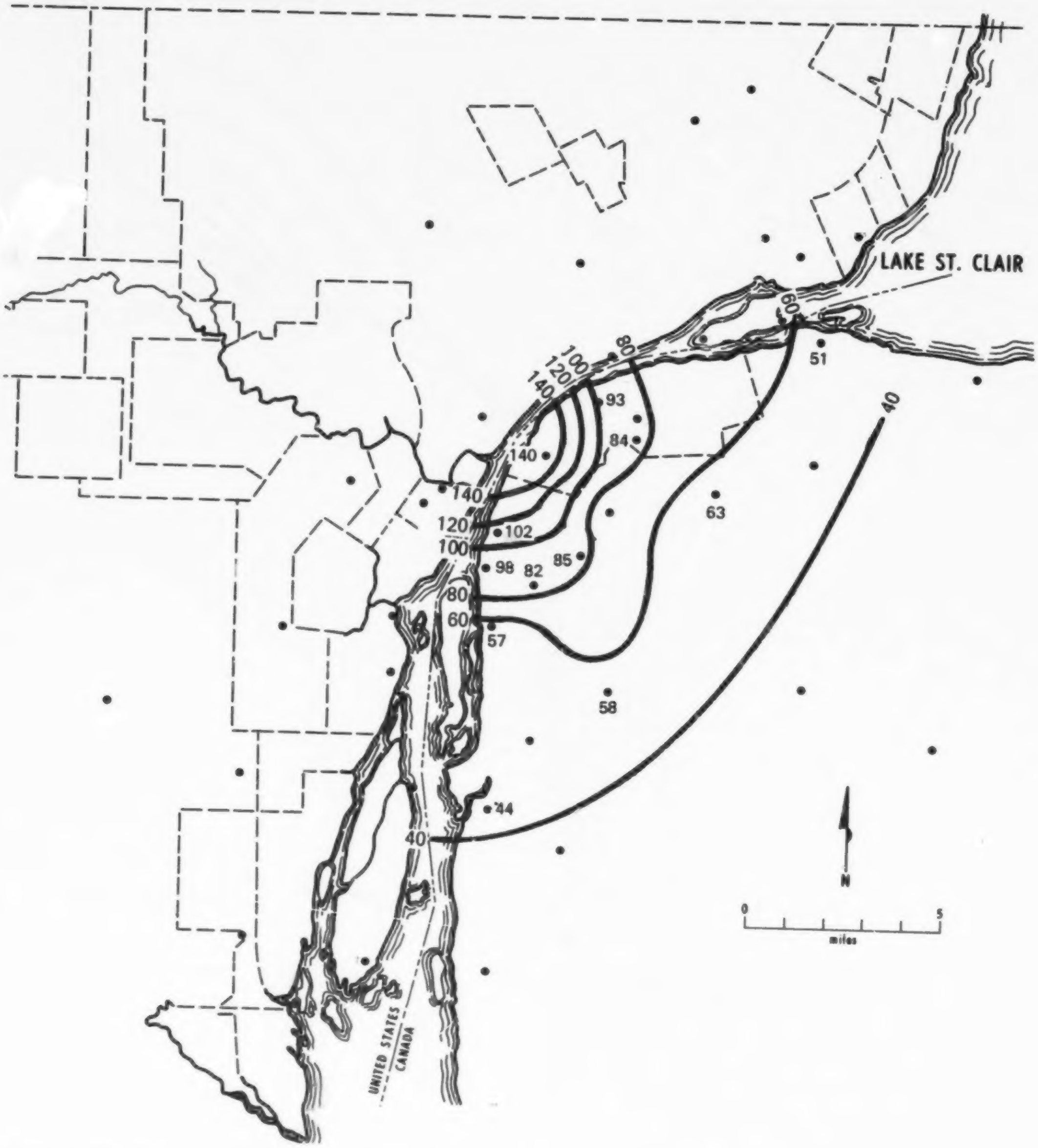

LAKE ST. CLAIR
60
80
100
120
140
93
84
140
51
40
140
120
100
102
63
98
82
85
80
60
57
58
44
40
N
0
5
miles
UNITED STATES
CANADA

Figure 4-25. Estimated contribution of U. S. sources to annual average concentrations of particles ($\mu g/m^3$) in Windsor area.

in the U. S. A portion of the SO_2 concentrations, however, would be contributed by Canadian sources.

The analyses of the incidence of high concentrations of pollutants at these stations verify that pollutants were transported across the international boundary.

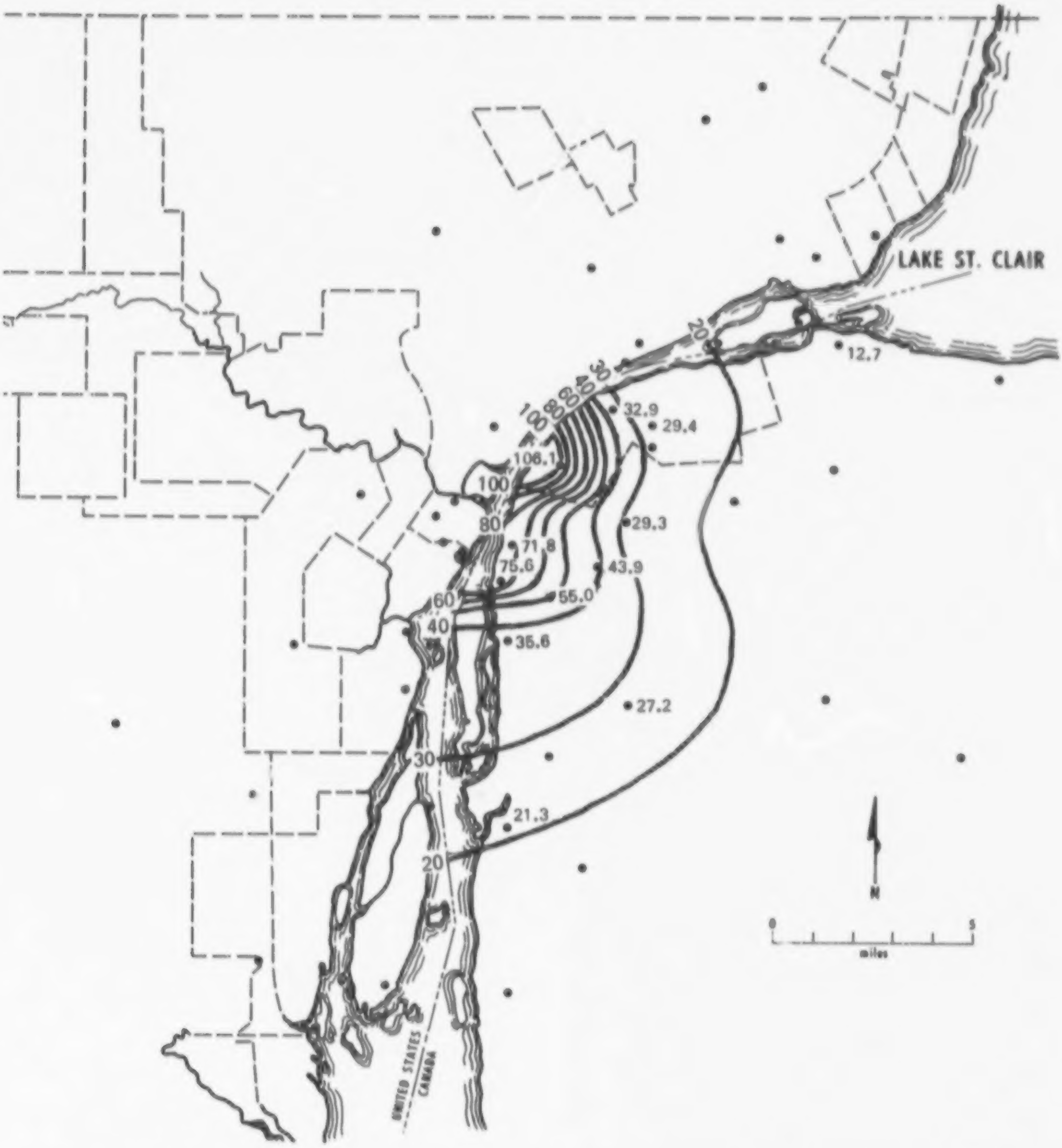

LAKE ST. CLAIR
20
12.7
100
80
60
40
30
32.9
29.4
106.1
100
80
71.8
75.6
29.3
43.9
55.0
60
40
35.6
27.2
30
21.3
20
N
0
5
miles
UNITED STATES
CANADA

Figure 4-26. Estimated contribution of U. S. point sources to annual average concentrations of particles (μg/m^3) in Windsor area.

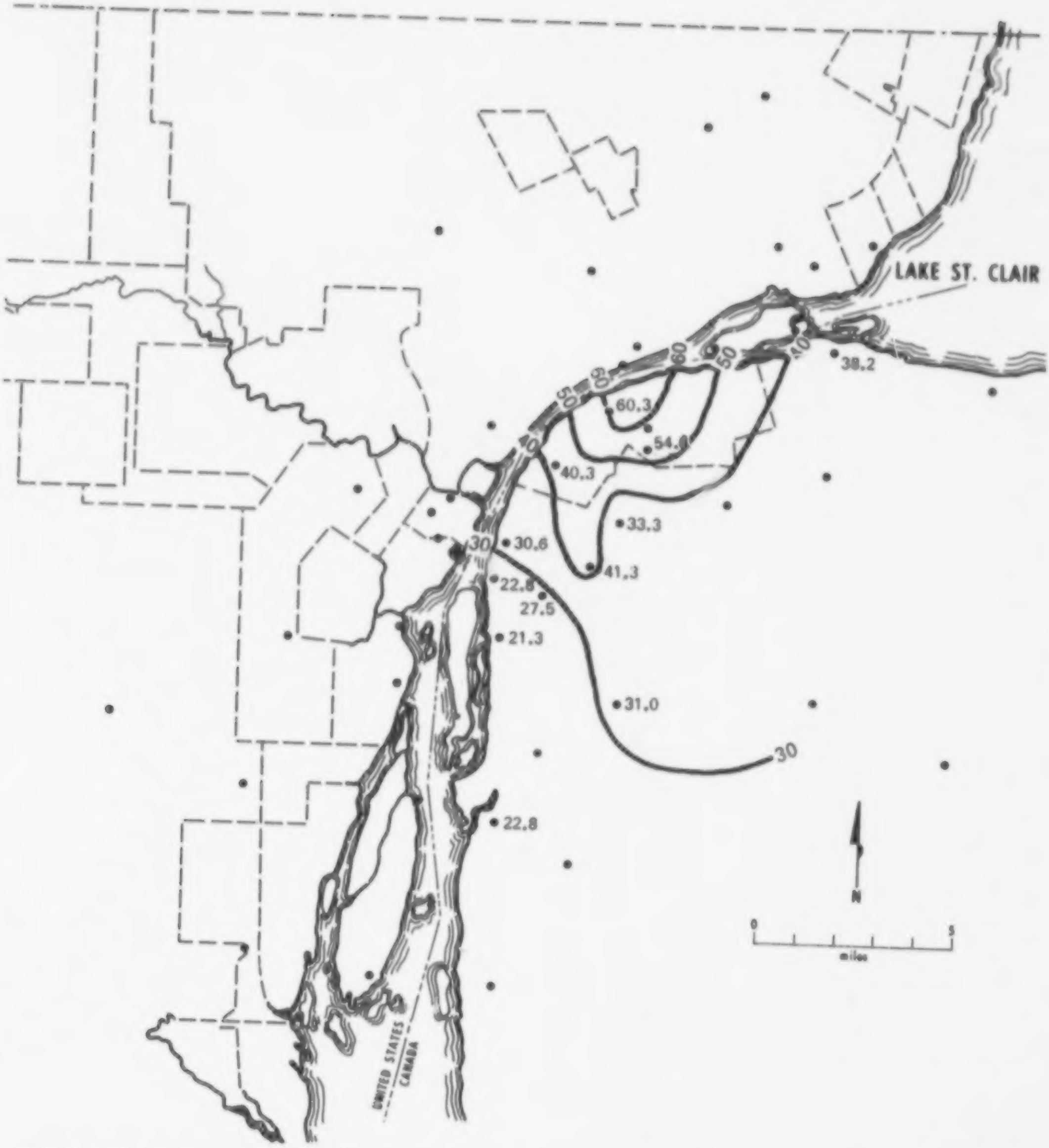

LAKE ST. CLAIR
60
60
50
50
40
40
30
30
60.3
54.6
40.3
38.2
33.3
30.6
41.3
22.8
27.5
21.3
31.0
22.8
UNITED STATES
CANADA
N
0
5
miles

Figure 4-27. Estimated contribution of U. S. area sources to annual average concentrations of particles (μg/m3) in Windsor Area.

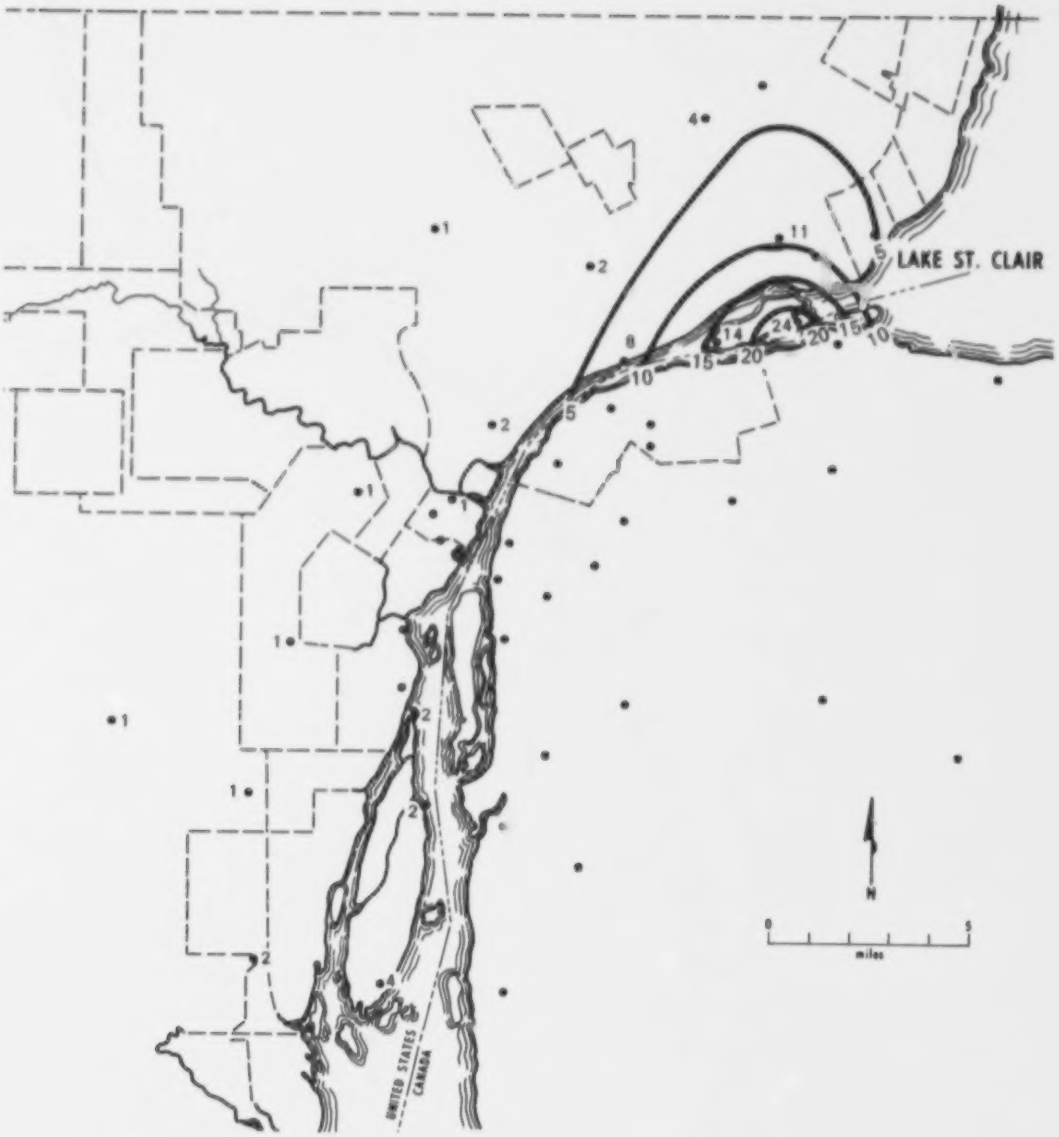

LAKE ST. CLAIR
4
11
5
8
10
14
24
20
15
20
15
10
1
2
2
1
1
1
1
1
2
2
2
4
N
0
5
miles
UNITED STATES
CANADA

Figure 4-28. Estimated contribution of Canadian sources to annual average concentrations of particles (μg/m^3) in Detroit area.

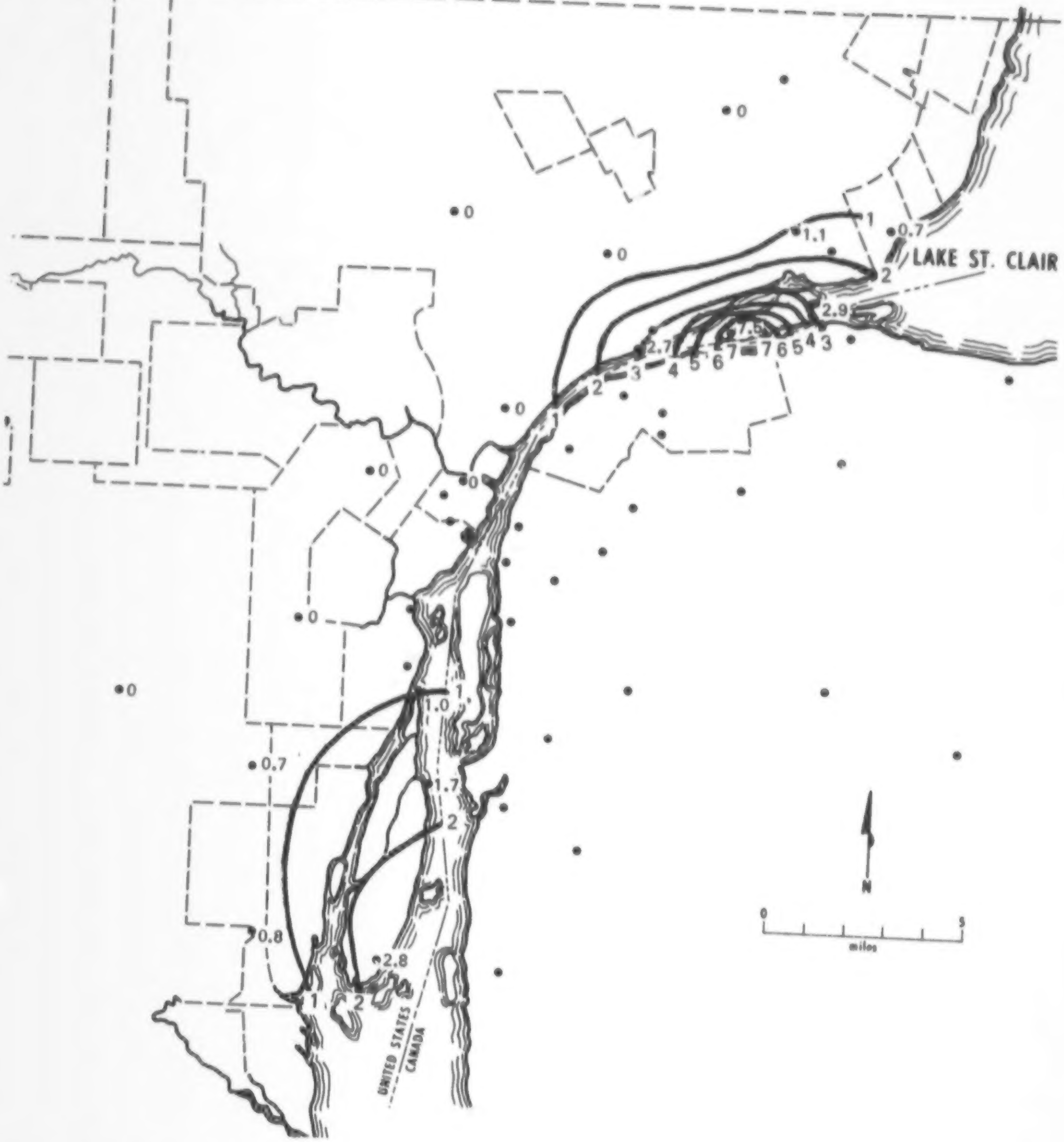

0
0
0
0
0
0
0
1.1
1
0.7
LAKE ST. CLAIR
2
2.9
7.5
2.7
2
3
4
5
6
7
7
6
5
4
3
1
1.0
1.7
2
0.7
0.8
2.8
1
2
UNITED STATES
CANADA
N
0
5
miles

Figure 4-29. Estimated contribution of Canadian point sources to annual average concentrations of particles (μg/m^3) in Detroit area.

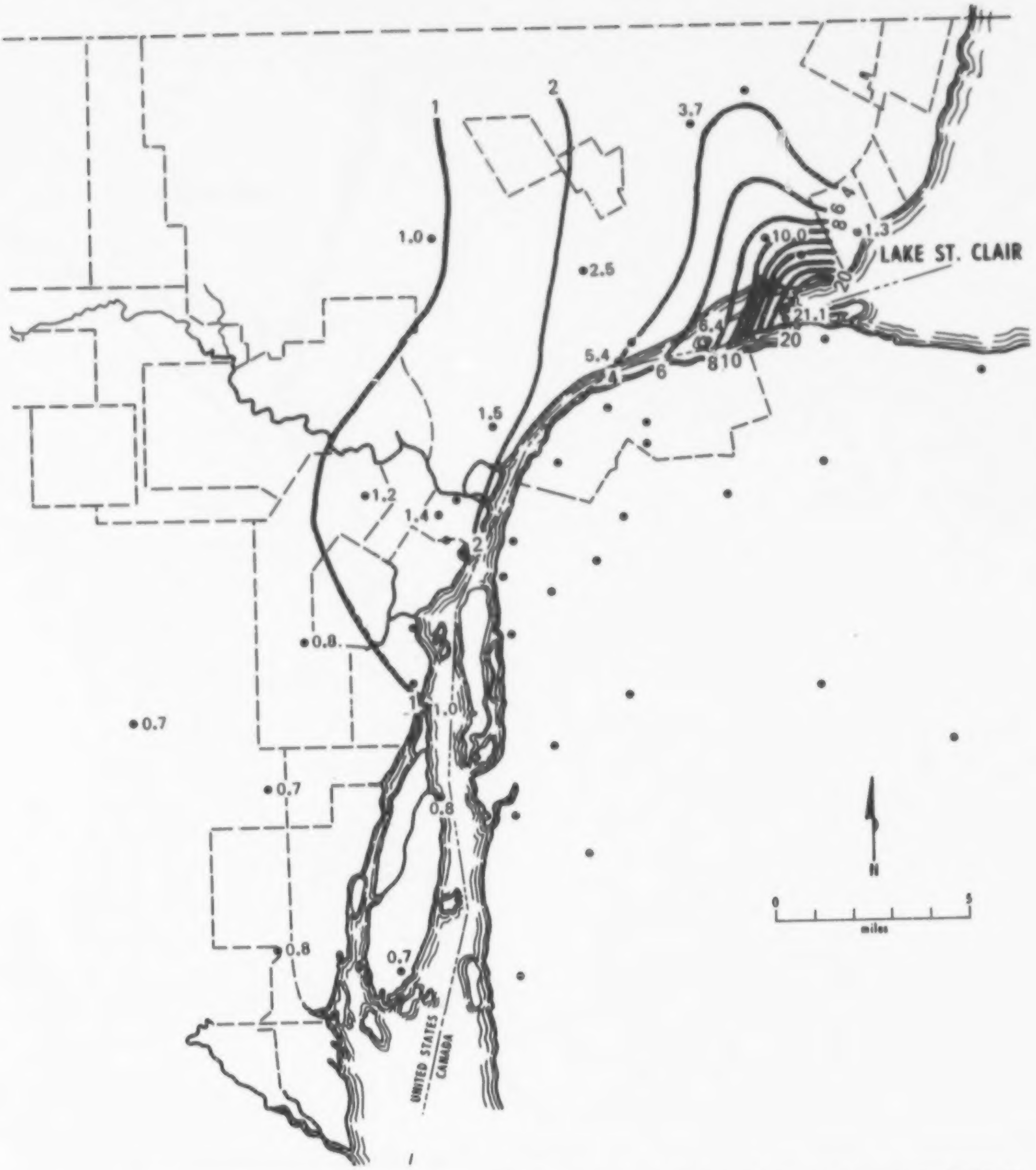

1
2
3.7
1.0
2.5
4
6
8
10.0
1.3
LAKE ST. CLAIR
20
21.1
20
6.4
5.4
4
6
8
10
1.5
1.2
1.4
2
0.8
1
1.0
0.7
0.7
0.8
0.8
0.7
UNITED STATES
CANADA
N
0
5
miles

Figure 4-30. Estimated contribution of Canadian area sources to annual average concentrations of particles (µg/m^3) in Detroit area.

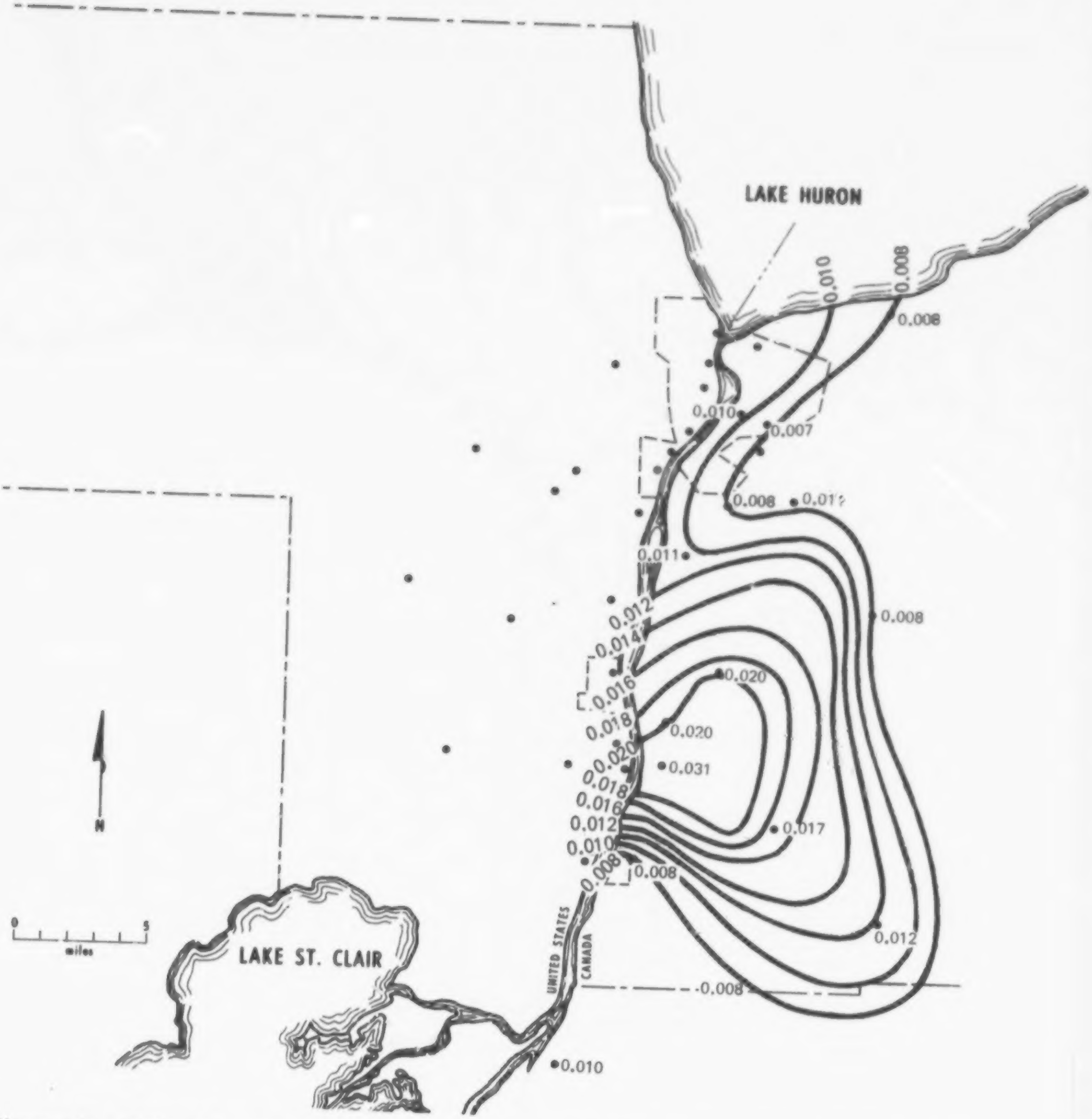

LAKE HURON
0.010
0.008
0.008
0.010
0.007
0.008
0.012
0.011
0.008
0.012
0.014
0.016
0.020
0.018
0.020
0.020
0.031
0.018
0.016
0.012
0.010
0.008
0.017
0.008
0.012
0.008
0.010
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-31. Estimated contribution of U. S. sources to annual average concentration of SO_2 (ppm) in Sarnia area.

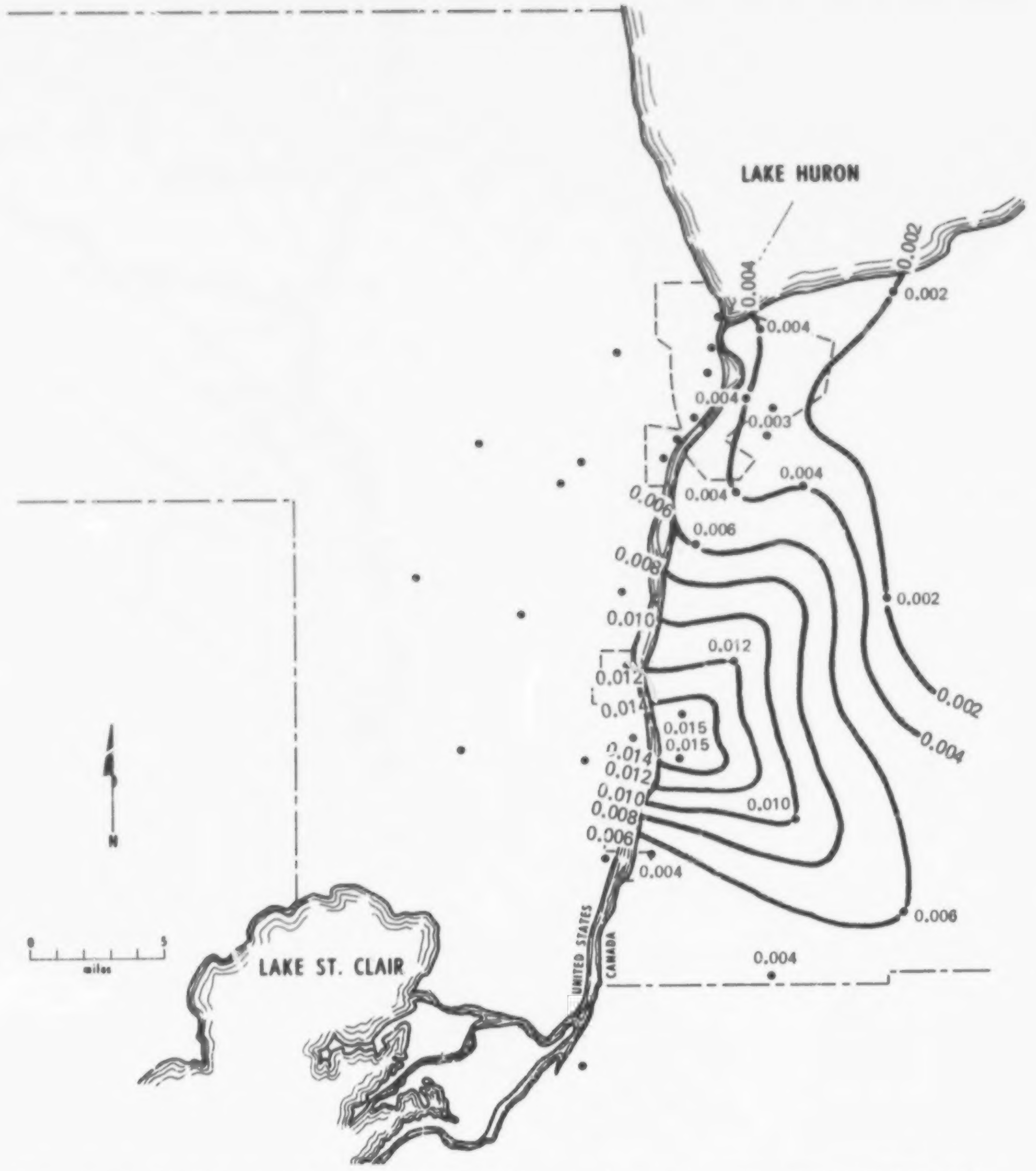

LAKE HURON
0.004
0.002
0.002
0.004
0.004
0.003
0.004
0.004
0.006
0.006
0.008
0.010
0.002
0.012
0.012
0.002
0.014
0.015
0.015
0.004
0.014
0.012
0.010
0.010
0.008
0.006
0.004
0.006
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA
0.004

Figure 4-32. Estimated contribution of U. S. point sources to annual average concentrations of SO_2 (ppm) in Sarnia area.

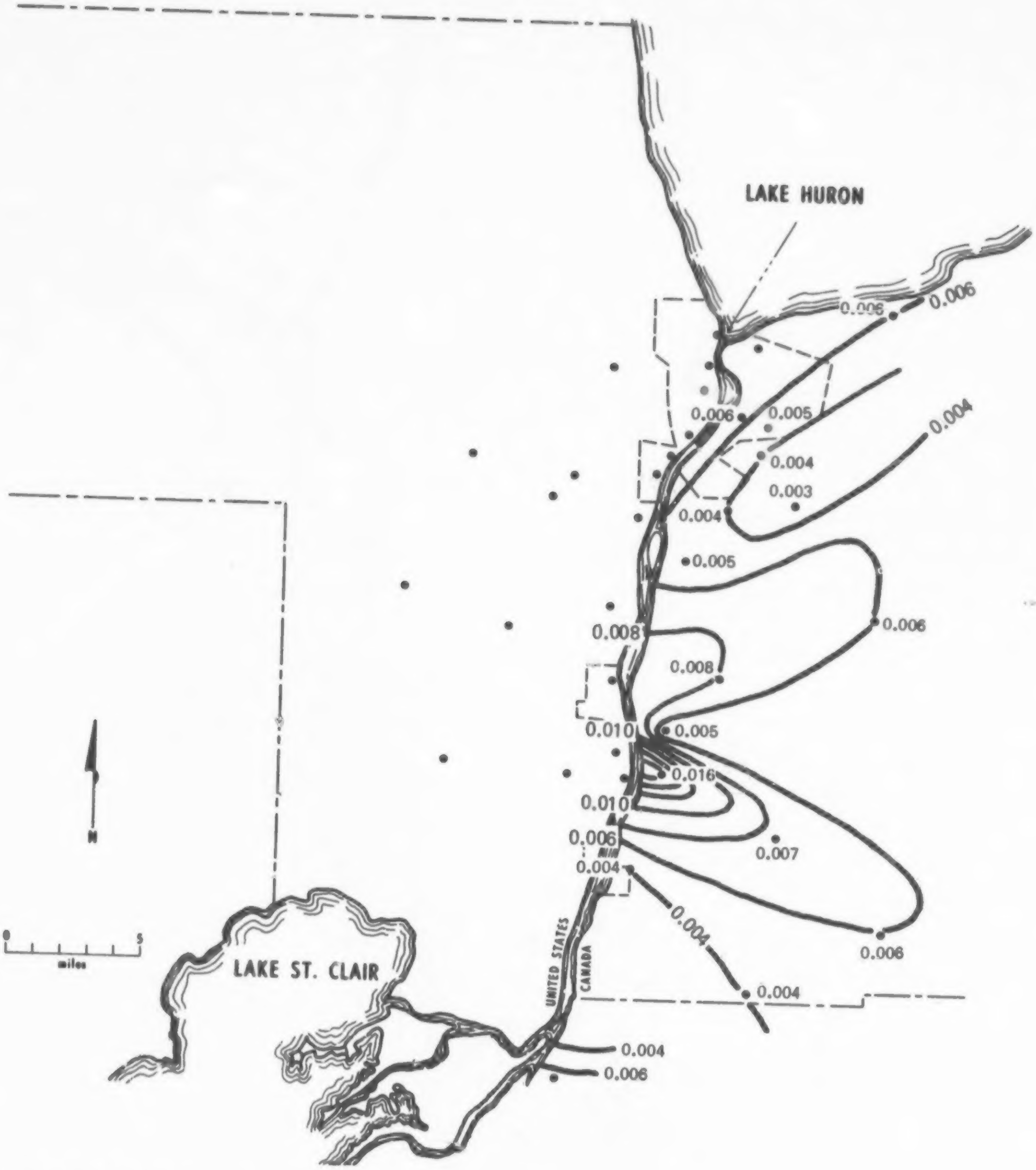

LAKE HURON
0.006
0.006
0.006
0.005
0.004
0.004
0.003
0.004
0.005
0.006
0.008
0.008
0.010
0.005
0.016
0.010
0.006
0.007
0.004
0.004
0.006
0.004
0.004
0.006
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-33. Estimated contribution of U. S. area sources to annual average concentrations of SO_2 (ppm) in Sarnia area.

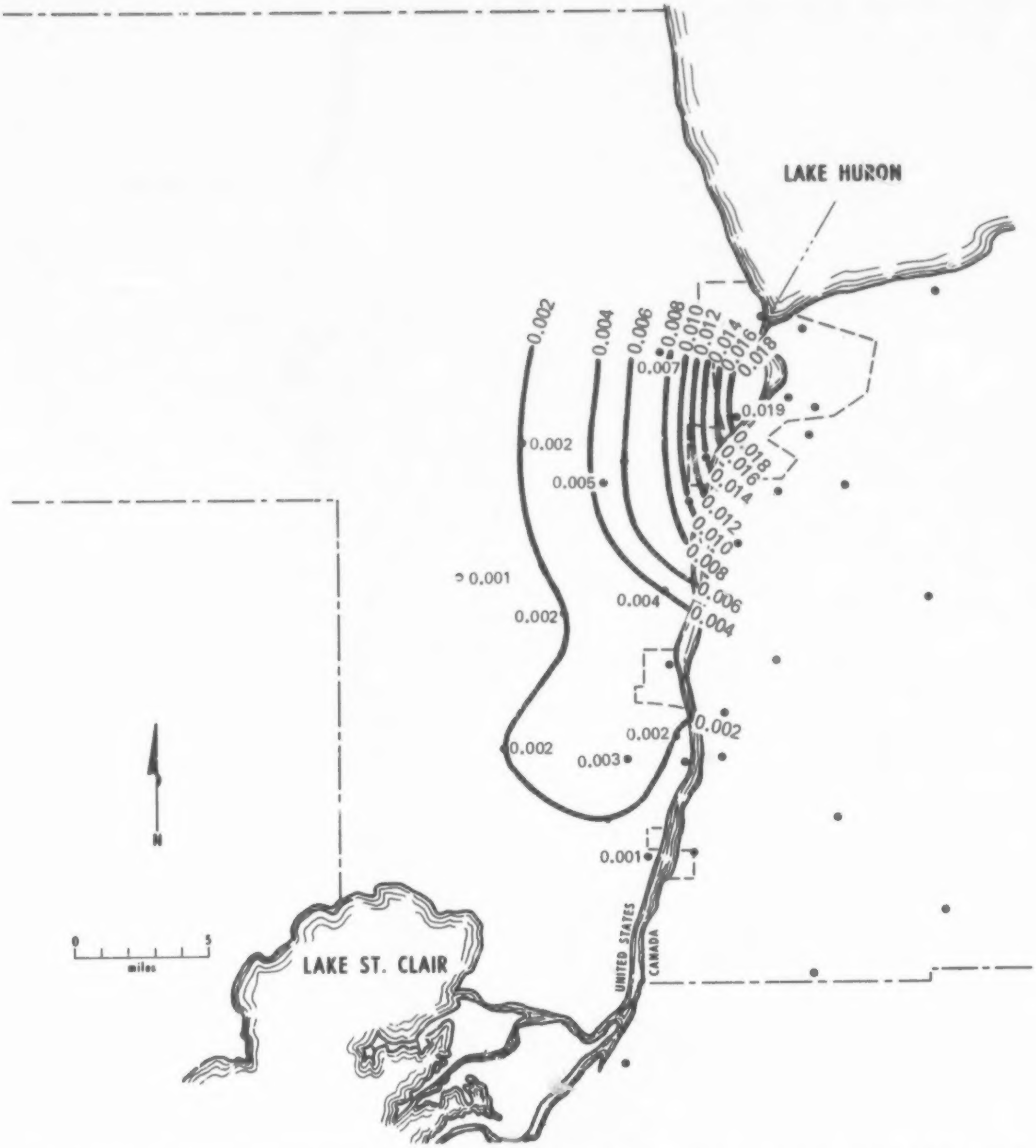

LAKE HURON
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.007
0.019
0.002
0.005
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.001
0.004
0.002
0.002
0.002
0.002
0.003
0.001
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-34. Estimated contribution of Canadian sources to annual average concentration of SO_2 (ppm) in Port Huron area.

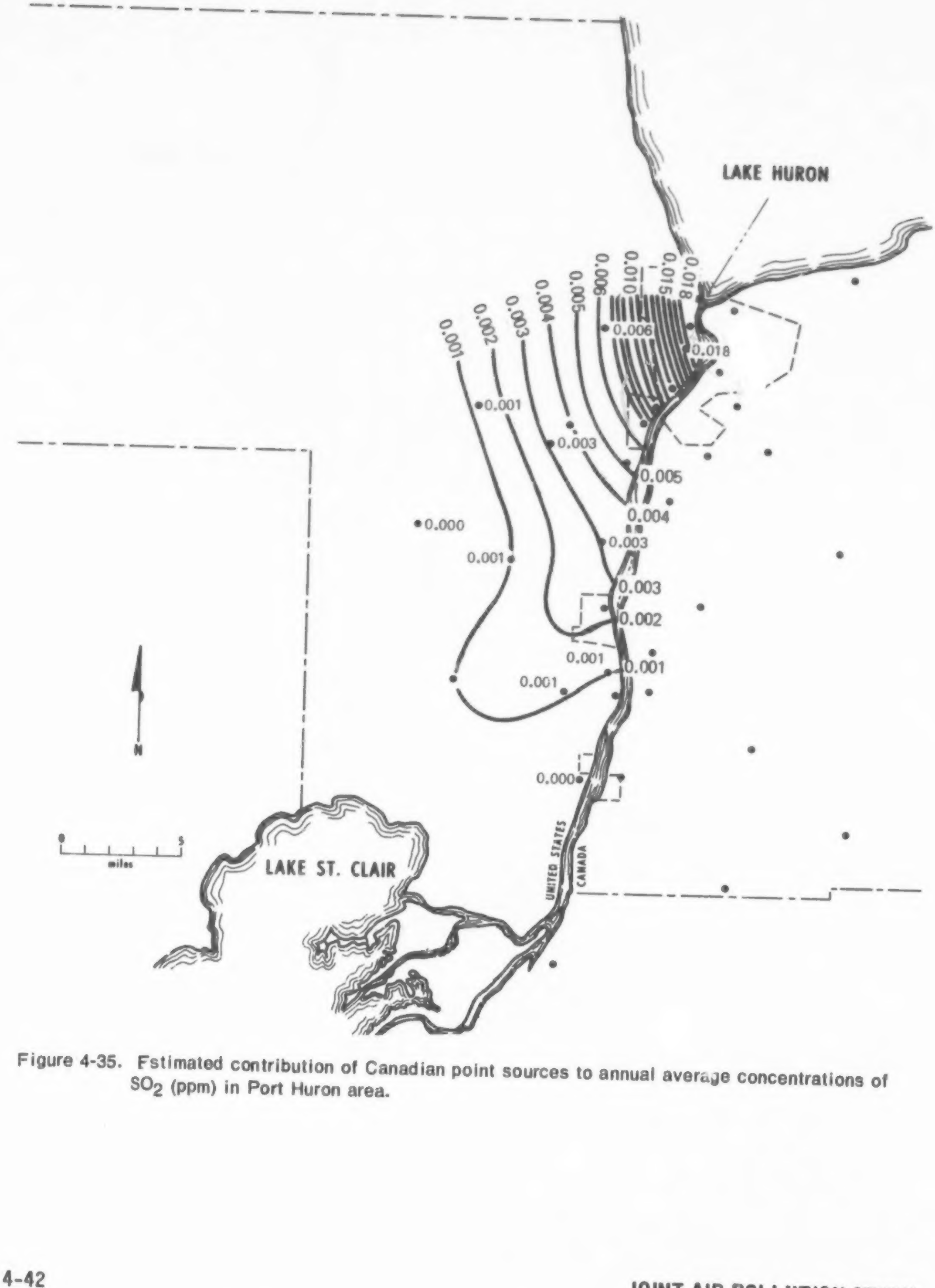

LAKE HURON
0.018
0.015
0.010
0.006
0.005
0.004
0.003
0.002
0.001
0.006
0.018
0.001
0.003
0.005
0.004
0.000
0.003
0.001
0.003
0.002
0.001
0.001
0.001
0.000
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-35. Estimated contribution of Canadian point sources to annual average concentrations of SO_2 (ppm) in Port Huron area.

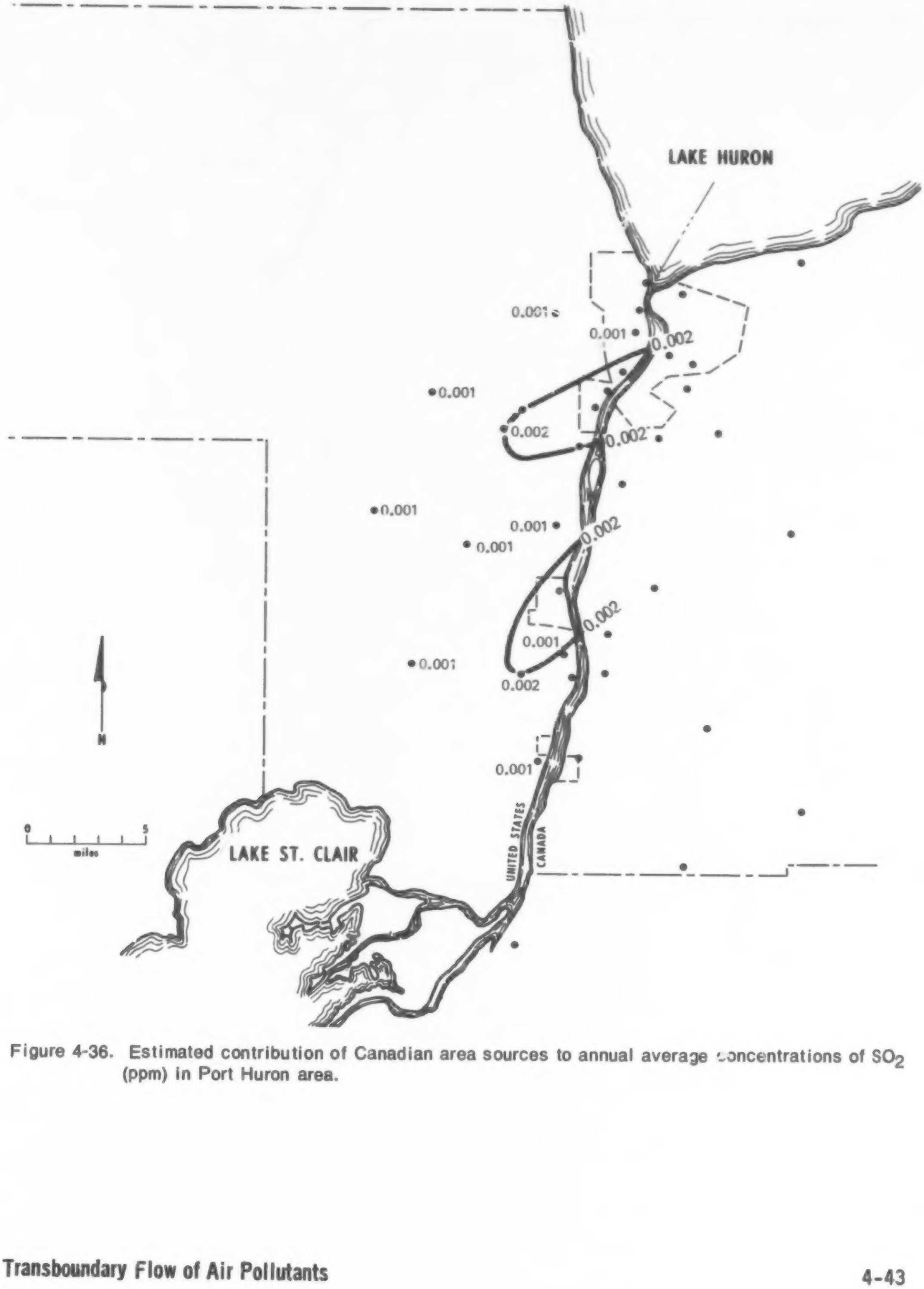

LAKE HURON
0.001
0.001
0.002
0.001
0.002
0.002
0.001
0.001
0.002
0.001
0.002
0.001
0.001
0.002
0.001
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-36. Estimated contribution of Canadian area sources to annual average concentrations of SO_2 (ppm) in Port Huron area.

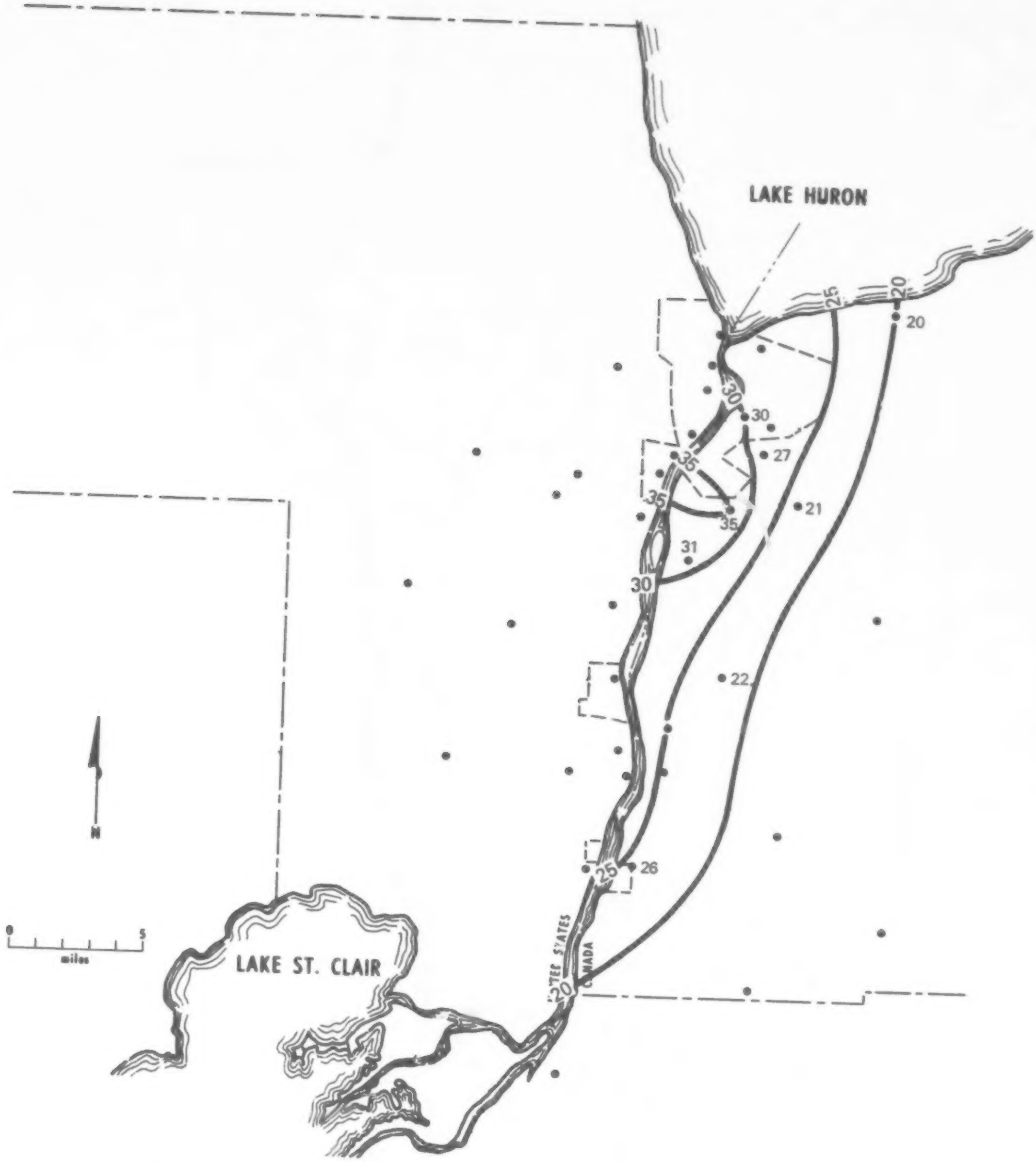

LAKE HURON
20
25
20
30
30
27
35
35
21
35
31
30
22
25
26
UNITED STATES
CANADA
20
N
0
5
miles
LAKE ST. CLAIR

Figure 4-37. Estimated contribution of U. S. sources to annual average concentrations of particles (μg/m3) in Sarnia area.

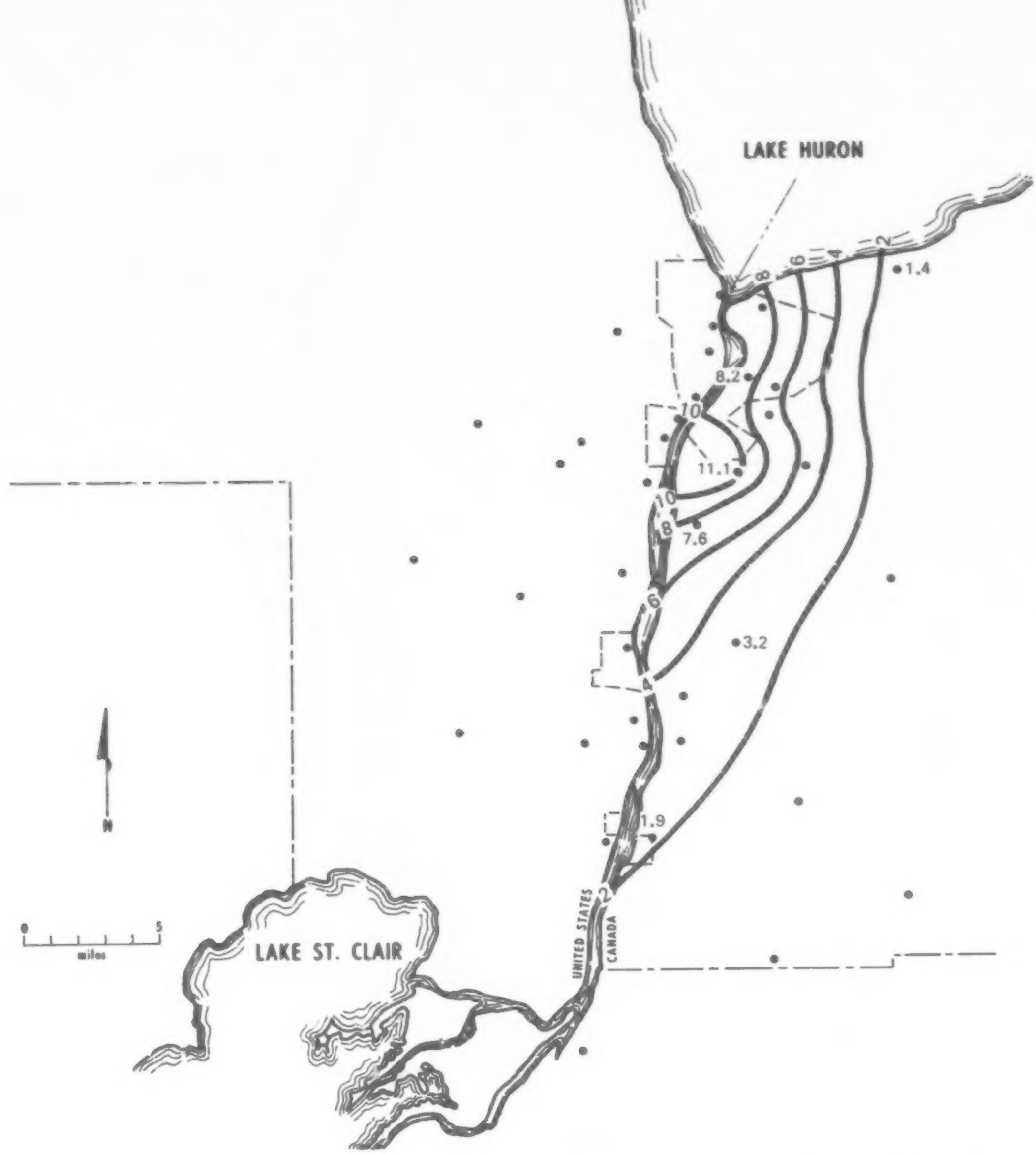
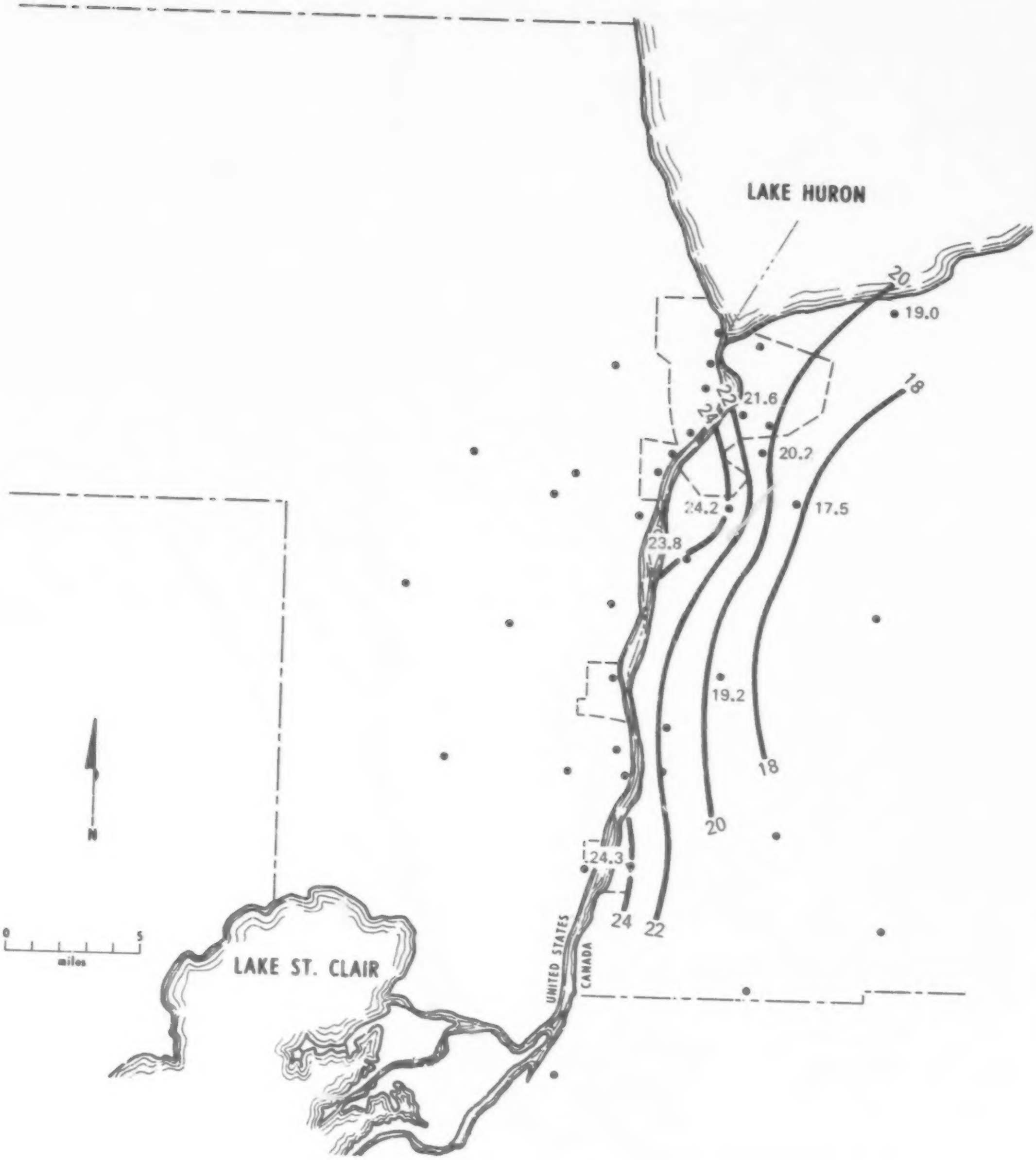

LAKE HURON
LAKE ST. CLAIR
UNITED STATES
CANADA
N
0
5
miles
1.4
8.2
11.1
7.6
3.2
1.9
2
4
6
8
10

Figure 4-38. Estimated contribution of U. S. point sources to annual average concentrations of particles (μg/m^3) in Sarnia area.


LAKE HURON
20
19.0
18
22
24
21.6
20.2
24.2
17.5
23.8
19.2
18
20
24.3
24
22
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Estimated 4-39. Estimated contribution of U. S. area sources to annual average concentrations of particles (μg-m^{-3}) in Sarnia area.

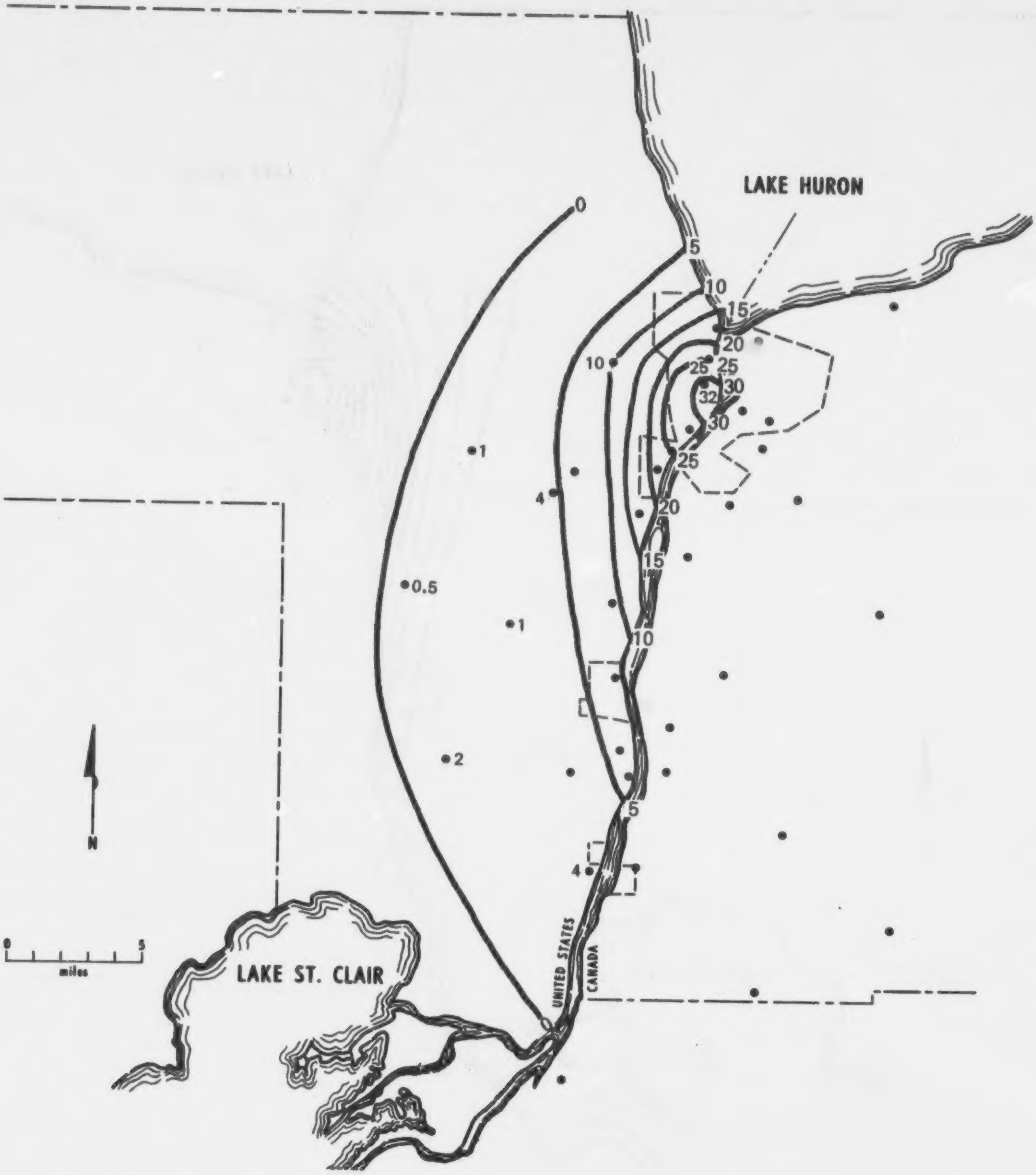

LAKE HURON
0
5
10
15
20
25
25
30
32
30
25
20
15
10
5
10
1
4
0.5
1
2
4
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-40. Estimated contribution of Canadian sources to annual average concentrations of particles ($\mu g/m^3$) in Port Huron area.

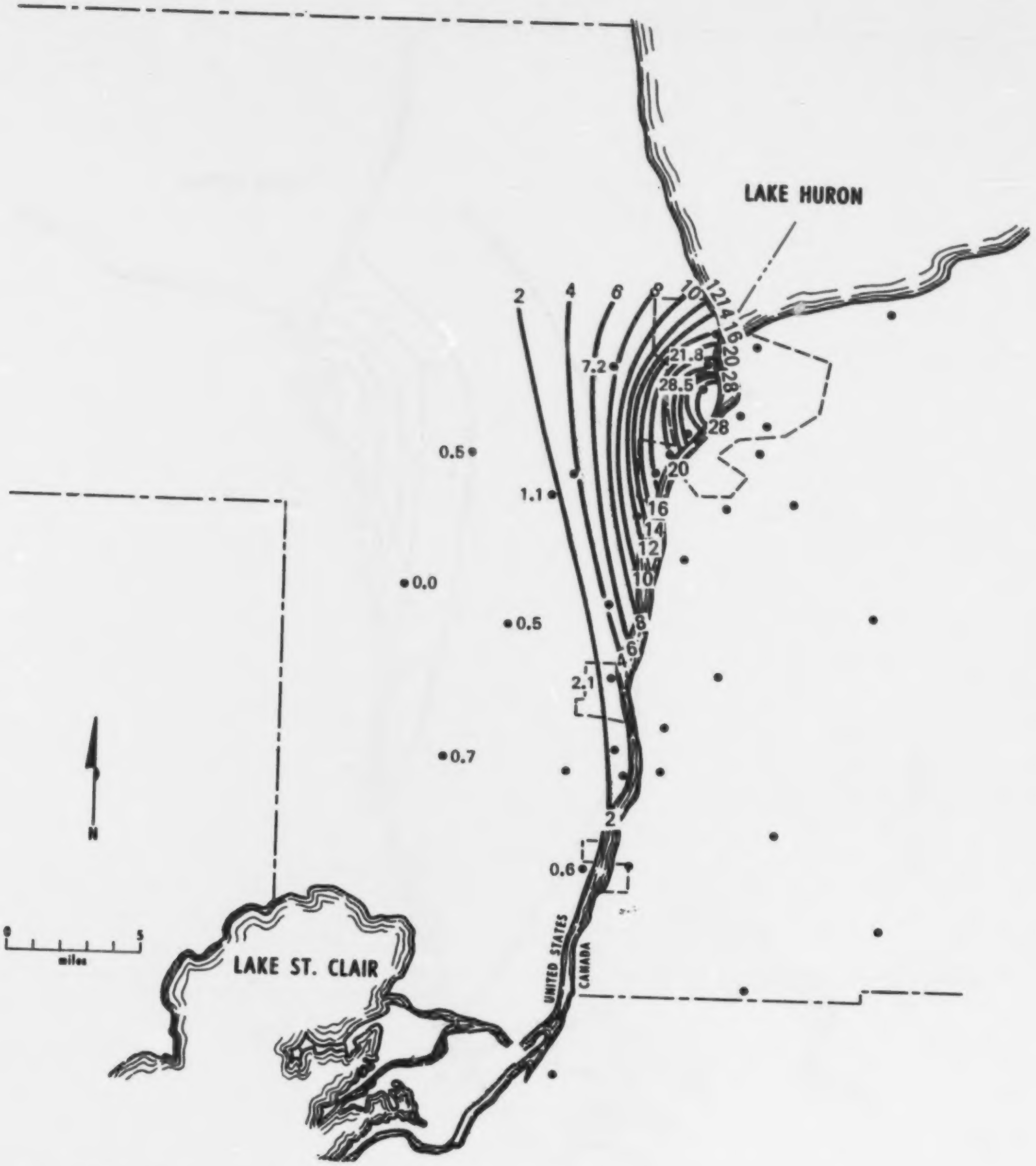

LAKE HURON
2
4
6
8
10
12
14
16
20
28
7.2
21.8
28.5
28
20
16
14
12
10
8
6
4
2.1
2
0.5
1.1
0.0
0.5
0.7
0.6
N
0
5
miles
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-41. Estimated contribution of Canadian point sources to annual average concentrations of particles (μg/m³) in Port Huron area.

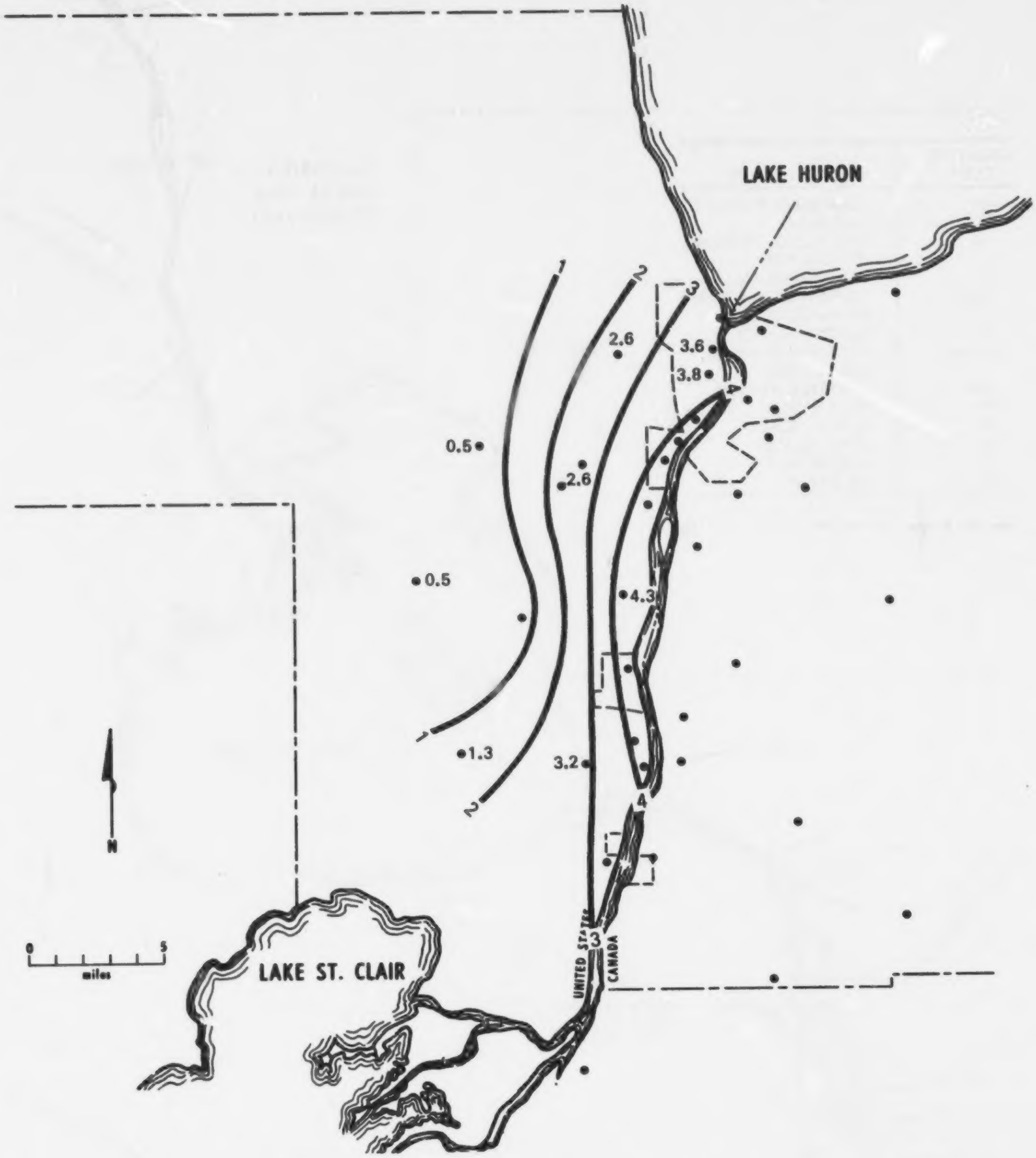

LAKE HURON
1
2
3
2.6
3.6
3.8
4
0.5
2.6
0.5
4.3
1
1.3
3.2
2
4
N
0
5
miles
3
LAKE ST. CLAIR
UNITED STATES
CANADA

Figure 4-42. Estimated contribution of Canadian area sources to annual average concentrations of particles (μg/m^3) in Port Huron area.

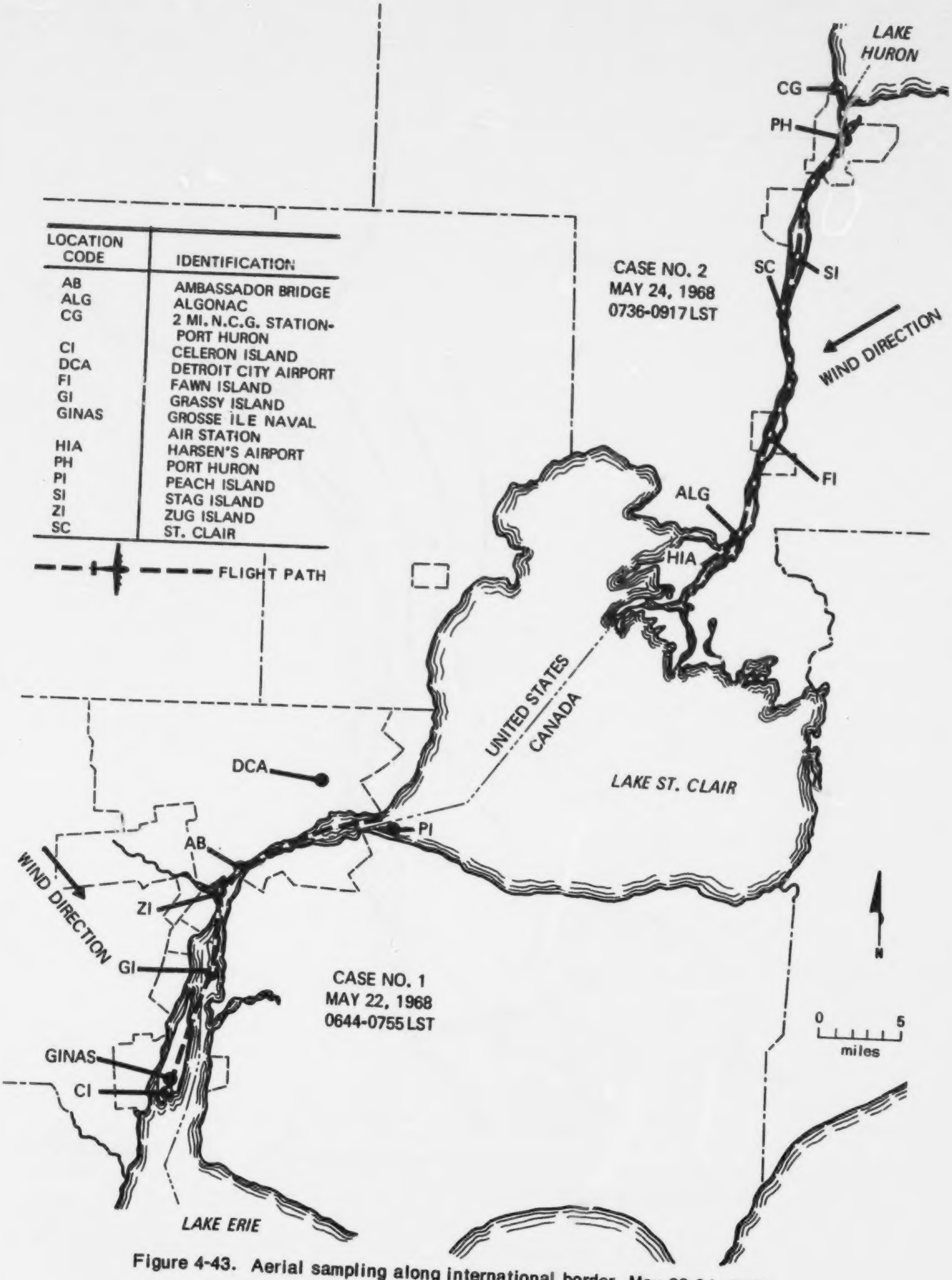

LOCATION CODE
IDENTIFICATION
AB AMBASSADOR BRIDGE
ALG ALGONAC
CG 2 MI. N.C.G. STATION-PORT HURON
CI CELERON ISLAND
DCA DETROIT CITY AIRPORT
FI FAWN ISLAND
GI GRASSY ISLAND
GINAS GROSSE ILE NAVAL AIR STATION
HIA HARSEN'S AIRPORT
PH PORT HURON
PI PEACH ISLAND
SI STAG ISLAND
ZI ZUG ISLAND
SC ST. CLAIR
FLIGHT PATH
LAKE HURON
CG
PH
SC
SI
CASE NO. 2
MAY 24, 1968
0736-0917 LST
WIND DIRECTION
FI
ALG
HIA
UNITED STATES
CANADA
LAKE ST. CLAIR
DCA
PI
AB
ZI
WIND DIRECTION
GI
CASE NO. 1
MAY 22, 1968
0644-0755 LST
GINAS
CI
LAKE ERIE
N
0 5
miles

Figure 4-43. Aerial sampling along international border, May 22-24, 1968.

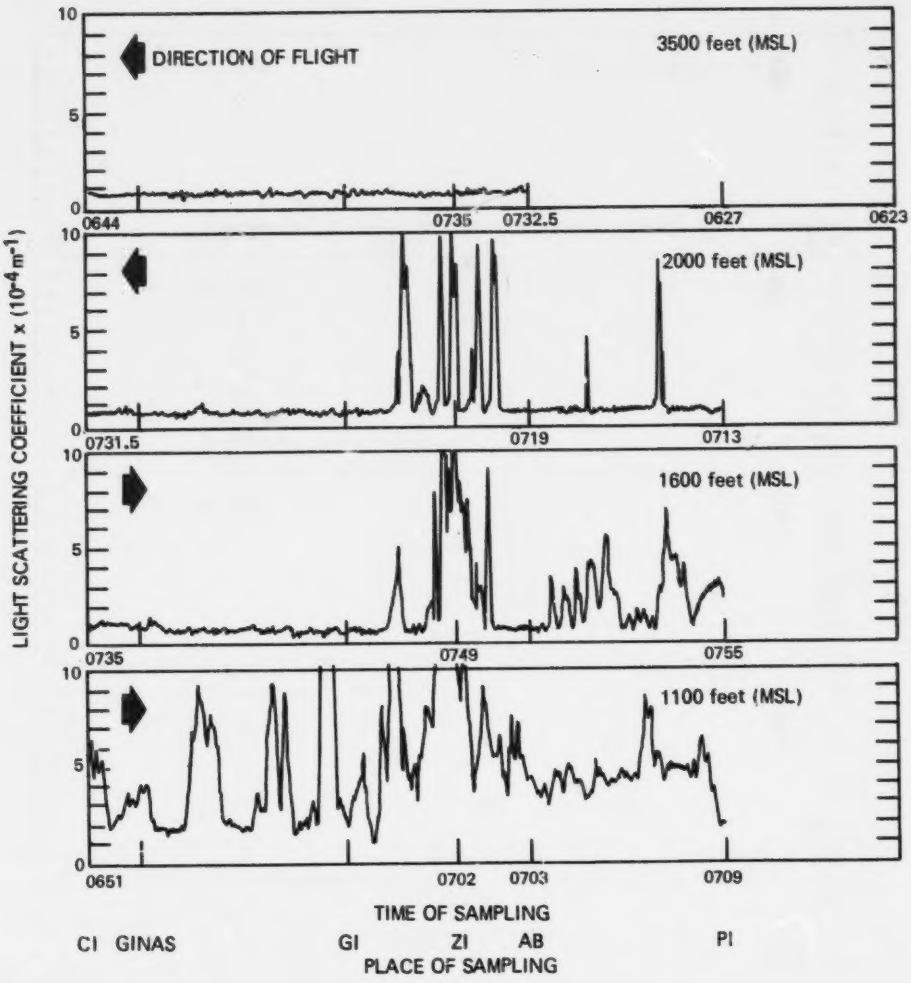


Figure 4-44. Suspended particulate aerial sampling traverses at various levels (Case No. 1 - May 22, 1968); Surface: 585 feet (MSL).

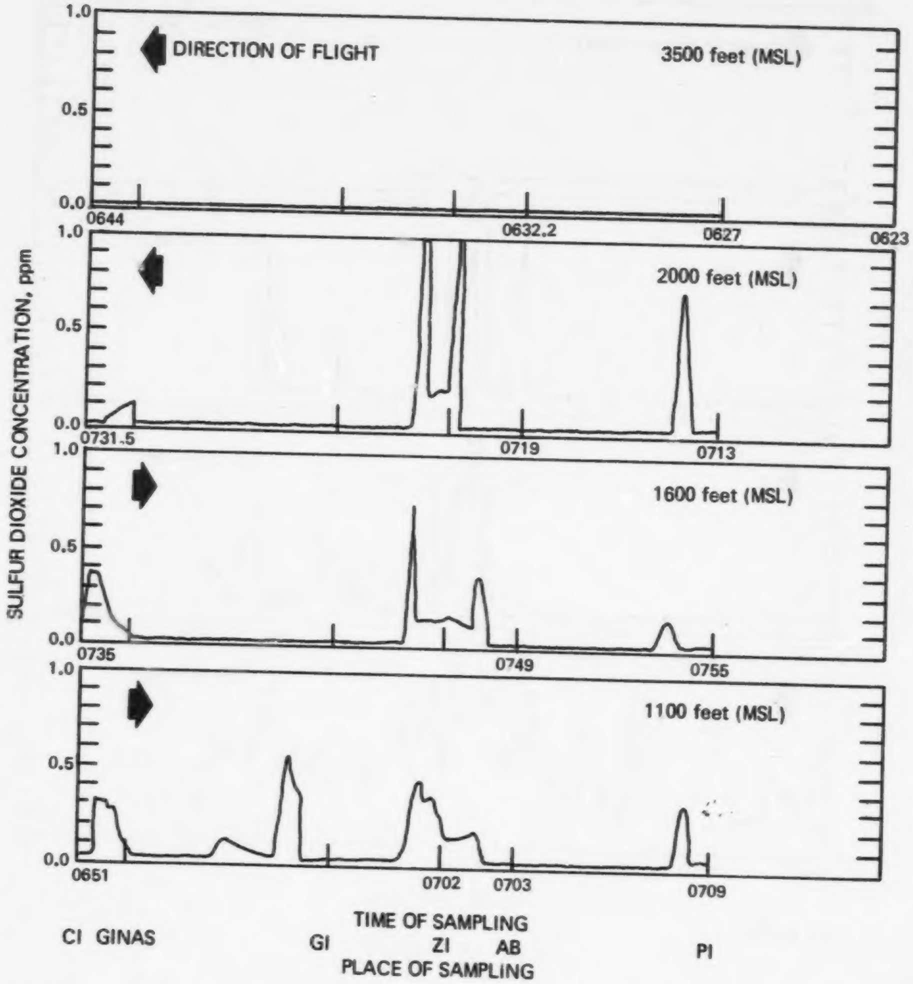


Figure 4-45. Sulfur dioxide aerial sampling traverses at various levels (Case No. 1 - May 22, 1968); Surface: 585 feet (MSL).

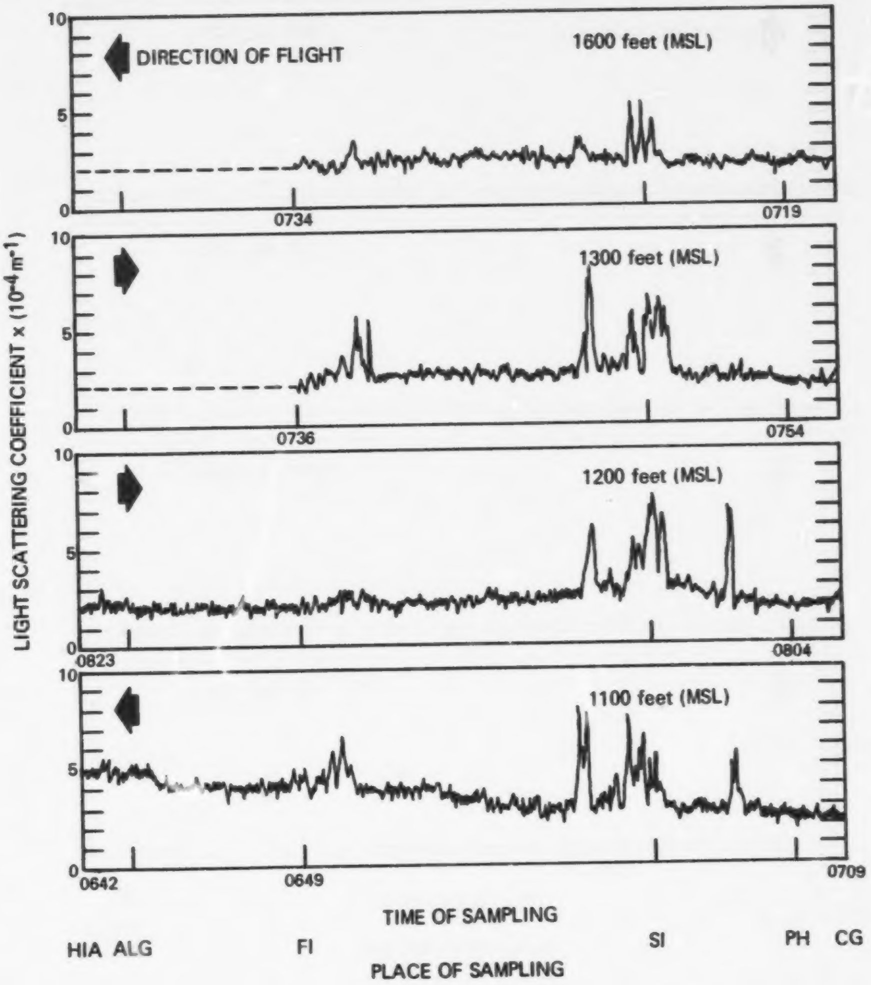


Figure 4-46. Suspended particulate aerial sampling traverses at various levels (Case No. 2 - May 24, 1968); Surface: 585 feet (MSL).

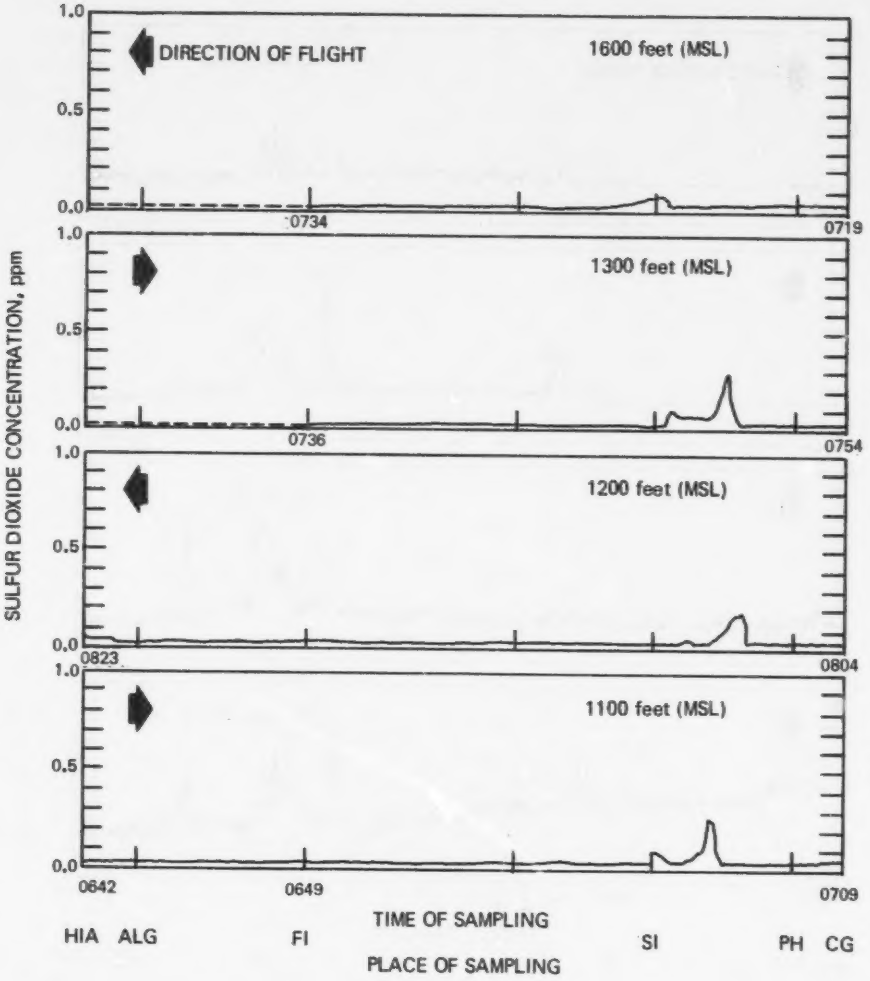
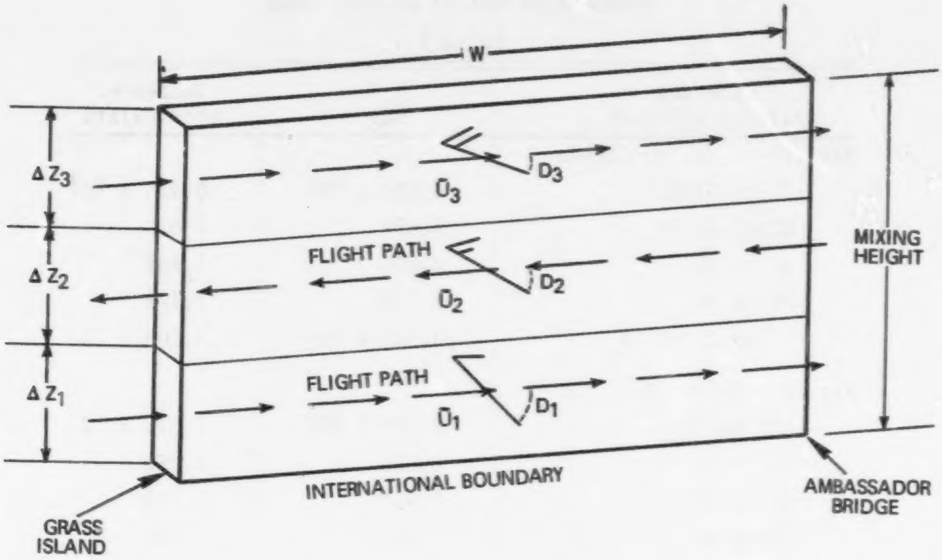


Figure 4-47. Sulfur dioxide aerial sampling traverses at various levels (Case No. 2 - May 24, 1968); Surface: 585 feet (MSL).


W
Δ Z3
Δ Z2
Δ Z1
Ū3
D3
FLIGHT PATH
Ū2
D2
FLIGHT PATH
Ū1
D1
MIXING HEIGHT
INTERNATIONAL BOUNDARY
GRASS ISLAND
AMBASSADOR BRIDGE

$$N = W \Delta Z \, \Sigma \bar{U} \, X \ \mathrm{SIN} \ D$$

N, g/sec = total amount of material moving through a vertical cross-section per unit time

W, meters = width of the cross-section

ΔZ, meters = height of the interval used to calculate the flux through the vertical layers up to the extimated mixing height

$\bar{U}$, meters/sec = mean wind speed for the layer

X, g/sec = mean concentration for the layer

D, degrees = angle between flight path line and the wind direction for the layer

Mixing height estimated from temperature measurements during vertical spiral ascents of the aircraft.

Figure 4-48. Method of computing mass transport. Schematic cross-section example for Detroit River.

Table 4-6. FLUX OF POLLUTANTS CROSSING INTERNATIONAL BOUNDARY ON MAY 22 AND 24, 1968
(g/sec)

Date and traverse interval	SO_2	Suspended particulate
May 22 - U. S. to Canada		
CI to GINAS[a]	2.502×10^3	0.326×10^3
GINAS to GI	1.872	1.090
GI to AB	4.406	1.601
AB to PI	2.762	1.186
Sum CI to PI	11.542×10^3	4.203×10^3
May 24 - Canada to U. S.		
HIA to FI	0.584×10^3	3.675×10^3
FI to SC	0.622	4.255
SC to SI	0.954	2.254
SI to PH	4.347	2.388
PH to CG	0.315	1.694
Sum HIA to CG	6.822×10^3	14.266×10^3

[a] Abbreviations are as follows:

CI	Celeron Island
GINAS	Grosse Ile Naval Station
GI	Grassy Island
AB	Ambassador Bridge
PI	Peach Island
HIA	Harsen's Island Airport
FI	Fawn Island
SC	St. Clair
SI	Stag Island
PH	Port Huron
CG	2 mi N of Coast Guard Station

Table 4-7. NUMBER OF OCCURRENCES FOR INDICATED WIND DIRECTIONS OF SOILING INDICES EXCEEDING 2.0 Coh/1,000 LINEAL FEET OR SO_2 CONCENTRATIONS EXCEEDING 30 ppm

Station number	Pollutant	Wind direction, degrees																			
		Calm	020	040	060	080	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total
310	Coh	1	2	0	1	0	0	0	4	14	4	10	1	1	1	1	1	1	2	2	46
156	SO_2	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	2	0	1	0	9
203	Coh	1	1	0	1	0	0	0	0	0	1	0	1	0	5	4	0	2	0	0	16
404	SO_2	1	0	0	0	0	0	0	0	1	5	3	0	0	0	2	0	0	0	0	12

4.5 REFERENCES FOR SECTION 4

1. Martin, D. O. and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at 61st Air Pollution Control Assoc. Meeting. Paper No. 68-148, 1968.

2. Adams, D. F. and R. K. Koppe. Instrumenting Light Aircraft for Air Pollution Research. J. Air Pollution Control Assoc. 19(6): 410-415, June 1969.

3. Charleston, R. J., N. C. Alquist, and H. Horvath. On the Generality of the Correlation of Atmospheric Aerosol Mass Concentration and Light Scatter. Atmospheric Environ. 2: 455, 1968.

5. CONTROL AGENCY ACTIVITIES

5.1 INTRODUCTION

The study has confirmed the fact that transboundary pollution occurs in both the Port Huron – Sarnia and the Windsor – Detroit areas and, further, that the ground-level or ambient concentrations at certain locations exceed established standards for sulfur dioxide and suspended particulate matter.

The dispersion model that has been used to estimate the annual ground-level concentrations of pollutants (sulfur dioxide and particulate matter) at receptor sites produces an approximate concentration value. Through manipulation of the model, the relative contributions from Canadian and United States sources to given receptor sites can be estimated, but these are approximations that depend upon the quality of the input data and meteorological parameters. The model can serve as a useful tool in the evaluation of an area-wide pollution problem, but it is best used as a trend indicator rather than as a source of precise and accurate information upon which definitive enforcement actions can be taken.

Three forceful and comprehensive air pollution control programs are being conducted in the study area by the Michigan Department of Public Health, the Ontario Department of Energy and Resources Management, and the Wayne County Health Department. The Michigan control agencies utilize source emission limits as one enforcement technique, and the limits that have been established are based upon the application of the best available control technology. Ontario utilizes design standards, stated in terms of a maximum 30-minute average concentration at the point of impingement, as the basis of its enforcement program. In addition, iron foundries and asphalt mixing plants are covered by specific regulations, as are automobiles. Ontario has established a series of ambient air quality goals that are representative of desirable air quality. Ambient air quality standards presently being established for Wayne, Oakland, Macomb, and St. Clair counties are expected to be compatible with those established in Ontario.

The agencies involved must apply remedial action; this is being done and will be continued. The present approach involves a continuing program of (1) air monitoring, (2) source sampling, (3) emission inventory evaluation, (4) meteorological observations, and (5) compliance activities.

These items are all essential parts of the control programs being implemented, all of which are being enforced on the basis of measured air quality coupled with up-to-date source information.

All sources, particularly coal-burning power-generating facilities and oil refineries, are included in the current control program activities of the agencies involved. In view of the ambient air quality standards, the attainment of reduced sulfur dioxide concentrations and particulate levels at receptor sites in Canada and the United States will probably require either the use of lower-sulfur-content fuel or the desulfurization of flue gases. The approach will be specific and will be applied on a progressive basis, as is dictated by air quality measurements and air quality needs.

At the same time, an emergency or alert program is being developed to enable immediate control action in the event of a stagnation episode. Although stagnation episodes are more significant in areas characterized by occasional or frequent inversions of durations in excess of 24 hours, and are not likely to occur in the study area, preparations will be made to cope with such problems on an emergency basis, should they occur.

A description of the control programs applied in the United States and Canada follows.

5.2 ONTARIO AIR POLLUTION CONTROL PROGRAM

The control of air pollution became the total responsibility of the Province of Ontario with the passing of the Air Pollution Control Act in 1967. The Act became effective by phases in various areas of the Province starting January 2, 1968. Prior to that time, control was a municipal responsibility.

5.2.1 Air Pollution Control Act of 1967

The salient features of the Act are as follows:

1. Authority to control new stationary sources of air pollution by requiring a certificate of approval before such new sources may be created. This provision also requires existing sources that are expanded, altered, or modified, to obtain a certificate of approval prior to such changes.
2. Authority to control and regulate all sources of air pollution through investigations by provincial officers and Orders of the Minister.
3. Establishment of an Air Pollution Control Advisory Board to review recommendations of a provincial officer and, after a hearing, to report those recommendations to the Minister.
4. Authority for the Minister, after investigation, to order the cessation of the discharge of any air contaminant. This happens in unusual cases in which such discharge creates an immediate and serious danger to the health of the public, and in which a delay in following the usual procedures under the Act would prejudicially effect the public.
5. Provision for a Board of Negotiation to negotiate the settlement of claims of persons who have suffered economic loss through damage to crops or livestock due to air pollution.
6. Authority to control and regulate the discharge of air contaminants from motor vehicles by setting standards of emission and by requiring that motor vehicles be equipped with systems or devices to abate or control the emissions of air contaminants.
7. Provision for investigation of air pollution problems and for research and educational programs in the field of air pollution.

5.2.2 Administration of the Act

The agency designated to enforce the Act and regulations is the Air Management Branch, Department of Energy and Resources Management.

This Branch is organized into the following sections: Abatement, Approvals Air Quality and Meteorology, Phytotoxicology, Automotive, and Laboratory. For administrative purposes, the Province has been divided into seven regions and the regions further subdivided into districts. The number of districts and the number of personnel assigned are dependent upon economic activity, population, and complexity of the air pollution problems in the region.

When the Branch was transferred from the Department of Health to the Department of Energy and Resources Management, the former department continued to provide advisory services by making available a physician whose primary functions are to advise on ambient air quality criteria and to investigate specific complaints of health effects. In addition, epidemiological studies are undertaken by the Department of Health

Because of the interrelationship of the air pollution control program and other government departments, a Pollution Control Advisory Committee has been established to coordinate the programs designed to control common pollution problems. This Committee is chaired by the Deputy Minister of Energy and Resources Management and the following departments are members: Mines, Lands and Forests, Agriculture and Food, Health, Energy and Resources Management, Municipal Affairs, and Ontario Water Resources Commission.

In the study area, provincial responsibility started December 9, 1968, with the opening of district offices in Windsor and Sarnia. This was essentially the beginning of the control of industrial sources of air pollution in the area, even though some progress had been made prior to that time.

5.2.3 Control Requirements

Smoke control enforcement is based on visual comparison with a smoke density chart. Number 2 density (40 percent black) is permitted for not more than 4 minutes in a half-hour period. When a new fire is started, Number 3 density (60 percent black) is permitted for 3 minutes in a 15-minute period. At all other times the smoke density must not be greater than 1 (20 percent black). In cases of equipment failure, permission may be granted to exceed the limitations.

For contaminants other than smoke emission limits are stated in terms of the one-half-hour concentration at the point of impingement. The point of impingement can be the face of a building or at the ground level. The contaminants for which these design standards have been set appear in Table 5-1.

Although it could be inferred that the design standard approach will permit unlimited use of tall stacks for dispersion, this is not the case in practice since dispersion is only permitted when no practical means exists for removing the pollutant at the source. In other words, dispersion is considered an interim measure only.

In addition to the general regulation, specific regulations have been promulgated for ferrous foundries, asphalt mixing plants, and automotive emissions.

All new sources must obtain a Certificate of Approval prior to construction.

When it is dealing with existing sources of air pollution, the control agency is required by legislation to conduct an emission survey and give a written report

Table 5-1. STANDARDS FOR EMITTED CONTAMINANTS

Item	Contaminant name	Units of concentration	Concentration at point of impingement	Period of time
1	Ammonia	ppm in air by volume	5.0 average	30 min
2	Beryllium	$\mu g/m^3$ air	0.01 average	30 min
3	Bromine	ppm in air by volume	0.01 average	30 min
4	Cadmium oxide	$\mu g/m^3$ air	10 average	30 min
5	Carbon bisulfide	ppm in air by volume	0.15 average	30 min
6	Carbon monoxide	ppm in air by volume	5.0 average	30 min
7	Chlorine	ppm in air by volume	0.1 average	30 min
8	Dustfall	$tons/mi^2$	15 total	30 days
9	Fluorides	ppb in air by volume	5.0 average	30 min
10	Hydrogen chloride	ppm in air by volume	0.04 average	30 min
11	Hydrogen cyanide	ppm in air by volume	1.0 average	30 min
12	Hydrogen sulfide	ppm in air by volume	0.03 average	30 min
13	Iron	$\mu g/m^3$ air	10 average	30 min
14	Lead	$\mu g/m^3$ air	20 average	30 min
15	Lime	$\mu g/m^3$ air	20 average	30 min
16	Nitric acid	$\mu g/m^3$ air	65 average	30 min
17	Nitrogen oxides	ppm in air by volume	0.25 average	30 min
18	Silver	$\mu g/m^3$ air	1 average	30 min
19	Sulfur dioxide	ppm in air by volume	0.3 average	30 min
20	Suspended particulate matter	$\mu g/m^3$ air	100 average	30 min

to the owner. The report lists operations that do not comply with the requirements and recommends necessary control measures, together with a time limit for compliance. The recommendations do not specify the means of control but rather the limitation to be met.

Should the owner accept the recommendations and time limit, the Minister of Energy and Resources Management issues an Order confirming the recommendations. The Order is a legal document, and failure to comply with it can result in prosecution. Upon conviction, an individual is liable to a fine of not more than $2,000; a corporation, on first conviction is subject to a fine of not more than

$5,000; and on each subsequent conviction, to a fine of not more than $10,000. In addition, each day the Act or the regulations or a Minister's Order are contravened constitutes a separate offense.

If the owner believes that the recommendations are unreasonable, he may request a hearing within 14 days by the Air Pollution Control Advisory Board. After the hearing, the Board advises the Minister whether the recommendations should be confirmed or changed and the Minister issues his Order in light of the Board's advice.

5.2.4 Air Quality and Meteorological Monitoring

Air Quality monitoring is carried out at 31 locations involving some 340 sampling sites.

Air quality data are telemetered to the central office at 10-minute intervals from the following continuous monitors: Sarnia, two sulfur dioxide, two carbon monoxide, two hydrocarbon, two oxides of nitrogen, two total oxidant, three spot samplers, and two hydrogen sulfide; Windsor, two sulfur dioxide, two spot samplers, and one each of carbon monoxide, hydrocarbon, oxides of nitrogen, and total oxidant; Hamilton, one each of sulfur dioxide, carbon monoxide, hydrocarbon, oxides of nitrogen, total oxidant, and spot sampler; Metropolitan Toronto, four sulfur dioxide, four carbon monoxide, four hydrocarbon, two oxides of nitrogen, two total oxidant, one hydrogen sulfide, and three spot samplers.

Meteorological data are also telemetered from four towers located at Sudbury, Hamilton, Courtright, and Metropolitan Toronto. In addition, two mobile monitoring vans and one mobile meteorological van are used for special studies.

An Air Pollution Index System started in Metropolitan Toronto in March 1970, will be extended to Windsor early in 1971. The Index provides for an Advisory Level, at which time sources are advised to make plans for the curtailment of operations. It also provides for an Alert Level, at which time curtailment of operations can be ordered. Failure to comply with the Order can result in summary action.

5.3 MICHIGAN AIR POLLUTION CONTROL PROGRAM

5.3.1 Legal Basis

The Air Pollution Control Section of the Michigan Department of Public Health is charged with the responsibility of conserving Michigan's air resources. The philosophy of the program is the control of all existing sources of air pollution and the prevention of new sources of air pollution in a reasonable but firm manner. This philosophy is incorporated in the Air Pollution Control Act 348, passed in 1965, and in the Rules and Regulations that were subsequently adopted under the provisions of the Act in August 1967.

Two companion laws enacted in 1965 serve to assist in air pollution control. One is the Tax Exemption Act 250, which provides for the exemption from locally assessed taxes of equipment installed primarily for the purpose of controlling air pollution. The other is the Solid Waste Disposal Act 87, which has resulted in progress in the handling and ultimate disposal of solid waste materials.

The air pollution control Rules and Regulations include the following main divisions:

1. Definitions.
2. Air-use approval; permit system; and installation and operation.
3. Emission limitations and prohibitions.
    a. Standards of density - Ringelmann Chart.
    b. Open burning - general and salvage.
    c. Limits on particulate matter.
        (1) Table 1 - Schedule of operations.
            Fuel-burning equipment.
            Incinerators.
            Steel manufacturing.
            Ferrous cupolas.
            Lime kilns.
            Asphalt batch plants.
            Cement manufacturing.
            Iron-ore pelletizing.
        (2) Table 2 - Process weight.
            Table for sources not specifically named.
    d. Air contaminant or water vapor - prohibitions.
4. Testing and sampling.
5. Air cleaning devices and collected contaminants.

One of the most important provisions of Act 348 pertains to the establishment of an Air Pollution Control Commission. The Commission, which meets monthly, has effectively supported the goals and objectives of the Air Pollution Control Section.

Michigan's air pollution control program activities, comprehensive in scope, have accomplished much in a relatively few years. Program activities are discussed in the next section.

5.3.2 Organization

The organizational structure of the state's air pollution control agency is illustrated in Figure 5-1.

5.3.3 Activities

5.3.3.1 Plant Visits - Early in the program it was recognized that certain categories of industries were more important polluters than others and would require a greater control effort. Accordingly, the utility and industrial coal-burning facilities, cement plants, asphalt-paving plants, grey-iron foundries, and pulp and paper-making facilities, among others, were identified, grouped, and assigned to specific personnel in an effort to bring about compliance with the Rules and Regulations. In addition, all other potential or actual sources of air pollution are evaluated on a planned program basis.

Many factors are involved in a company's decision to take the steps necessary to achieve control of one or more operations, and these factors include the complexity of the control system required and the costs involved.

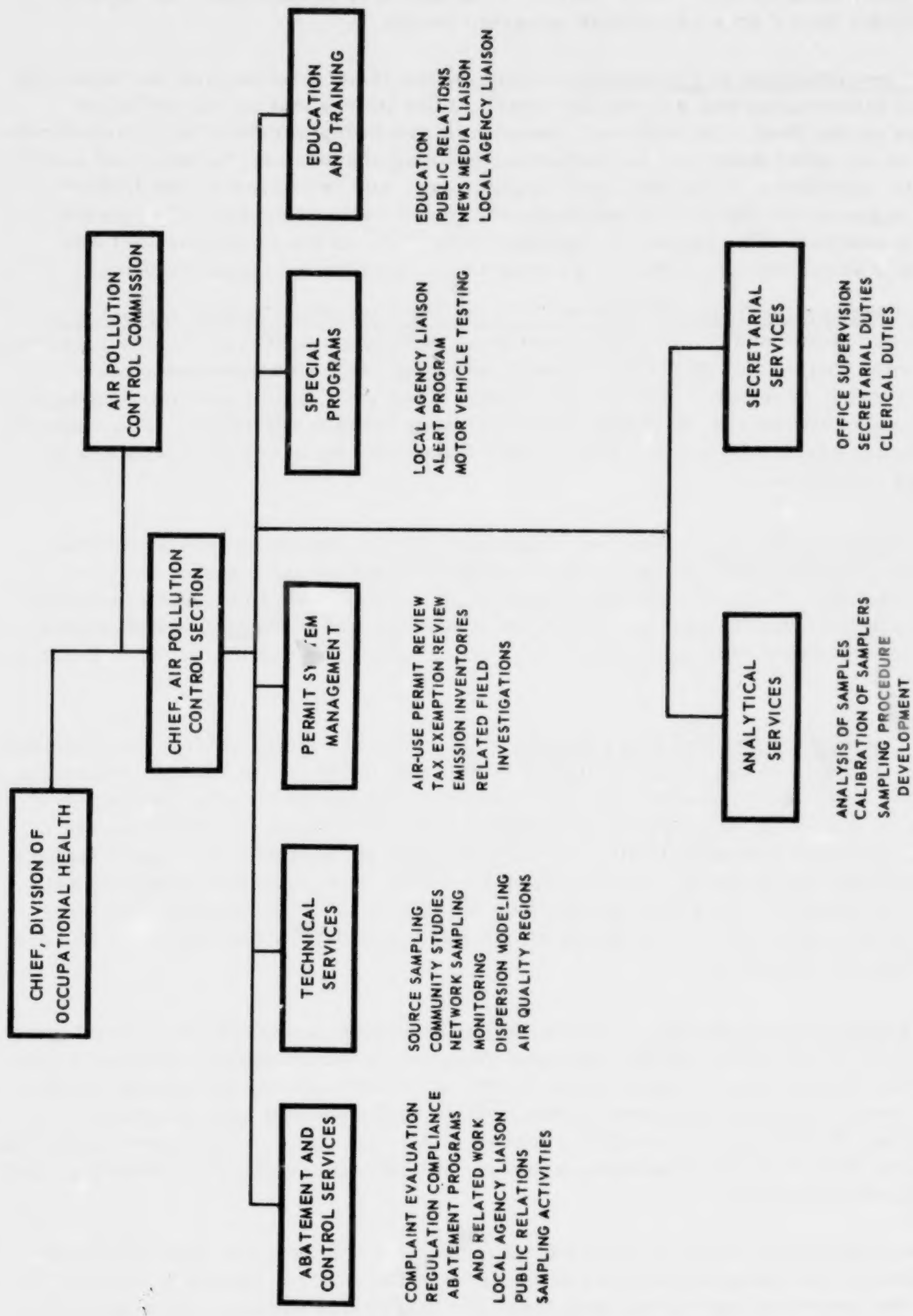

CHIEF, DIVISION OF OCCUPATIONAL HEALTH
AIR POLLUTION CONTROL COMMISSION
CHIEF, AIR POLLUTION CONTROL SECTION
ABATEMENT AND CONTROL SERVICES
COMPLAINT EVALUATION
REGULATION COMPLIANCE
ABATEMENT PROGRAMS AND RELATED WORK
LOCAL AGENCY LIAISON
PUBLIC RELATIONS
SAMPLING ACTIVITIES
TECHNICAL SERVICES
SOURCE SAMPLING
COMMUNITY STUDIES
NETWORK SAMPLING
MONITORING
DISPERSION MODELING
AIR QUALITY REGIONS
PERMIT SYSTEM MANAGEMENT
AIR-USE PERMIT REVIEW
TAX EXEMPTION REVIEW
EMISSION INVENTORIES
RELATED FIELD INVESTIGATIONS
SPECIAL PROGRAMS
LOCAL AGENCY LIAISON
ALERT PROGRAM
MOTOR VEHICLE TESTING
EDUCATION AND TRAINING
EDUCATION
PUBLIC RELATIONS
NEWS MEDIA LIAISON
LOCAL AGENCY LIAISON
ANALYTICAL SERVICES
ANALYSIS OF SAMPLES
CALIBRATION OF SAMPLERS
SAMPLING PROCEDURE DEVELOPMENT
SECRETARIAL SERVICES
OFFICE SUPERVISION
SECRETARIAL DUTIES
CLERICAL DUTIES

Figure 5-1. Organization of Michigan's Air Pollution Control Agency.

In instances in which progress is found to be inordinately slow, or nonexistent, the companies or individuals involved are asked to appear before the Air Pollution Control Commission and they, along with the air pollution staff representatives, have an opportunity to state their cases. In practically all instances acceptable arrangements based on a committed program evolve.

5.3.3.2 Investigation of Complaints - Complaints from citizens are an important source of information and account for much of the time spent by air pollution engineers in the field. In addition, complaints are being received at an accelerating rate from other sources, including neighboring industries, commercial establishments, members of the Michigan Legislature, and members of the United States Congress and Senate. Frequently the press calls attention to problems requiring control. The agency is familiar with many of the problems that are complained about and are actively working to bring about a prompt solution.

5.3.3.3 Cooperative Work Efforts with Local Air Pollution Control Agencies - The Michigan Rules and Regulations have been suspended in Wayne County inasmuch as the Wayne County Health Department is administering a comprehensive air pollution control program. In fact, the Wayne County air pollution control program plays an important part in Michigan's air pollution control activities. The county's supporting legislation is similar to the state's and the two agencies cooperate in controlling pollution.

5.3.3.4 Source Sampling - Because of the experience and equipment at its disposal, the Air Pollution Control Section is able to conduct all types of source-sampling studies. There is always a backlog of emission studies to be conducted in order to determine: emission rates, compliance or non-compliance with emission limits, the pollutants emitted by a given source, and the performance of collection equipment.

5.3.3.5 Community Air Pollution Studies - Special community studies are frequently conducted, either because the community has requested them or because special problems exist and require evaluation. Such studies usually involve the setting up of a network of air-sampling stations in a community in order to ascertain levels of pollution, to identify contaminants, and to correlate air pollution with such factors as meteorology, topography, and land-use patterns. A mobile air-sampling network that is supported by a data acquisition system is used as an adjunct to conventional techniques, which are based on the 30-day sulfation rate sampler and the high-volume air sampler.

5.3.3.6 Emission Inventories - The emission inventory is essentially a cataloging of all sources of air pollution by types and amounts of contaminants released to the atmosphere within a given geographical area. A variety of data-gathering techniques are used, ranging from door-to-door visits to the mailed questionnaire. Typically the objective is to evaluate sources of air pollution such as manufacturing and service, fuel-burning stationary sources, incineration and refuse burning, and motor vehicle emissions.

An emission inventory is quite useful if the data are kept current to demonstrate year-by-year improvements resulting from the control agency's efforts. In addition, the inventory serves as data input for dispersion models. Evaluations of inventories have revealed improvements and permitted projections of future levels of improvement in conjunction with knowledge of control programs being implemented in industry.

5.3.3.7 Permit System - The air-use permit system is utilized to ascertain control activities in industry and to establish effective liaison between industry and the control agency staff. The permit system not only provides information on control techniques that are being planned but also gives the staff the opportunity to advise industry on whether the chosen approach toward control of the problem is reasonable and has a good chance of success. When it is known that a control plan cannot work, a change can be brought about through denial of an installation or operation permit.

5.3.3.8 Tax Exemption - Tax exemption applications are submitted to the Tax Commissioner's office, which in turn refers them to the Air Pollution Control Section for review. Most air pollution control installations are covered by such applications and the information is invaluable in gauging the extent of the work being done in air pollution control. The opportunity to review such applications also enables the staff to determine whether applications for permits to install systems have been submitted and, if not, to ask that this be done.

5.3.3.9 Mobile Air-Sampling Network - The mobile air-sampling network consists at the present time of one central and three satellite trailers, all containing data-retrieval systems and capable of being interconnected by telephone lines. They are used not only for general community studies, where the total system can be utilized, but also for special problem area studies where one, two, or three trailers may be used. The use of only part of the system is particularly suitable for determining levels of pollutants generated by one or more plants in a limited area in a community. At the present time, for example, two trailers with automatic air-sampling equipment are deployed to determine the amount of sulfur dioxide emitted from a power plant. This approach is also suitable for correlating contaminant concentrations and meteorological conditions. A similar approach can be used to evaluate the intrastate and interstate transport of air pollutants.

Stack-gas dispersion models have already been developed through the utilization of a computer program and predictions of ground-level concentrations of sulfur dioxide have been made for many localities in Michigan. Sampling systems are now being used to compare predicted levels of sulfur dioxide with actual levels at given locations.

5.3.3.10 Basic Air-Sampling Network - The air-sampling network that utilizes equipment such as high-volume air samplers and lead peroxide plates is now being operated in 17 cities and will be enlarged to include other areas. The air-sampling techniques are relatively simple, imposing a minimum time requirement on personnel, but the amount of laboratory analyses required is formidable and is an important consideration in the deployment of sampling equipment. Nevertheless, network data permit the comparison of pollution levels in different cities in Michigan and in other parts of the United States.

5.3.4 Objectives

5.3.4.1 Short-Range Objectives - Program objectives are both short- and long-range. Immediate objectives include the following:

5.3.4.1.1 Identification of sources. One objective is the identification of all sources of air pollution in Michigan and development of programs for control of these sources. Identification is accomplished, by planned visits in response to complaints or on a self-initiated basis, through a systematic approach to different categories of industries, such as foundries, asphalt plants, coal-burning operations, cement plants, paper plants, and chemical manufacturers. When air pollution problems are encountered, discussions are held with the management about control. Commitments that delineate the type of control procedures to be applied on a scheduled basis are required of polluters. Wherever possible, assistance is given to those industries that need technical help and an effort is made to keep management informed of up-to-date control technology.

5.3.4.1.2 Determination of ambient levels of contaminants. A program has been established to determine ambient levels of certain contaminants in Michigan's communities. Four mobile air-sampling trailers are equipped with continuous-air-sampling devices and are being deployed in different cities for 2- to 3-week periods during each season of the year. The air is sampled for sulfur dioxide, oxides of nitrogen, carbon monoxide, and hydrocarbons; meteorological measurements are also made. The sampling program is to be extended to include measurements of other contaminants for which ambient air quality criteria will be adopted by the Federal government. The sampling data obtained permit assessment of the need for additional, more extensive sampling and stricter air pollution control in the communities involved. The data are also indicative, to some extent, of compliance with ambient air quality standards that are established.

5.3.4.1.3 Control of source categories. Control of certain categories of sources is accomplished through a deliberately planned program. Included among those categories of industries known to be serious potential sources of air pollution are the grey-iron foundries, the industrial and utility coal-burning power plants, asphalt-paving plants, cement plants, paper plants, several chemical manufacturers, and junk car burners. The program dealing with specific sources has resulted in improved control or in commitments for control that are to be achieved within the next few years.

5.3.4.2 Long-Range Objectives - The long-range objectives (3 to 5 years) of Michigan's air pollution control program are based to a large extent on the need to effect a significant reduction in air pollution levels despite anticipated increases in industrial activity and population. This is to be accomplished through the appropriate allocation of staff efforts and the effective utilization of air-sampling equipment. Among those specific objectives to be attained are the following:

1. Satisfactory control of all major industrial sources of air pollution.
2. Development of a timetable based on specific commitments for the control of all remaining sources of air pollution.
3. Establishment of an emission inventory system to computerize data-handling procedures. County inventory data are to be updated at least biannually.
4. Development and application of ambient air quality standards throughout the state.
5. Elimination of all open burning whether it be for solid or liquid waste disposal or for salvage purposes.
6. Initiation of local community action that will control air pollution nuisance sources such as the burning of refuse on private property, the burning of

leaves, and other unsatisfactory domestic procedures.

7. Development of a data bank covering all controlled installations in Michigan. This will serve not only as an indication of what has been done and what is being done, but also as an important source of information on control technology.
8. Development of knowledge pertaining to total use of the environment and the the effects on the environment from air pollution. This includes the development of up-to-date information on land use, highway construction, demographic planning, transportation systems, industrial development, fuel use, and the extent of transport of air pollution from neighboring states and from Canada.
9. Participation in a motor vehicle testing program in conjunction with the program utilized by the Federal government.

5.4 WAYNE COUNTY AIR POLLUTION CONTROL PROGRAM

5.4.1 Legal Basis

The Air Pollution Control Division of the Wayne County Department of Health was officially established in December of 1965 In December 1968, the Wayne County Board of Supervisors approved the transfer of the air pollution control program of the City of Detroit to the Wayne County Department of Health under provisions of Michigan State law.

By virtue of the State's enabling legislation, the Wayne County Board of Health adopted and promulgated the Wayne County Air Pollution Control Regulation with countywide jurisdiction involving 43 separate governmental entities in the County's 622 square miles.

Generally, the county regulations provide the Division with the legal authority to prevent, abate, and control air pollutants from all sources, existing and potential, within the County.

The Division is accomplishing this task through two basic methods:

(1) Improvement of the quality of the air by correcting existing sources of pollution.
(2) Prevention of further deterioration of the environment by exercising approving authority over municipal, commercial, industrial, and residential activities, including permits for various types of control devices.

5.4.2 Organization

At full strength, the Wayne County air pollution control staff will number approximately 86 people assigned to three main operating sections: Enforcement, Engineering, and Technical Services. Other supporting sections, equally important to the success of the Division's operations, are: Administrative Services, Legal, and Public Information sections.

The Enforcement Section, consisting of engineers and combustion-equipment inspectors is responsible for enforcing the County's air pollution control regulations through: (1) self-initiated surveillance of emission sources, (2) periodic inspection of process and fuel-burning equipment and their control devices, and (3) issuance of violation notices.

Field inspectors often work with the Engineering staff to provide assistance and direction to facilities needing control equipment and/or guidance in an abatement program in order to comply with the Regulations.

An additional and important task the field inspector performs daily is the answering of citizen complaints, most of which are valid and justified, and range from backyard rubbish fires to the serious, tons-per-day, emissions from local industries or power plants. Regardless of their nature, all complaints are answered, usually within 24 hours.

The inspectors also serve as witnesses whenever the Division resorts to court action to achieve abatement action. Current agency court action is averaging 200 cases per year, which result from approximately 6000 formal violation notices per year.

The Engineering Section has a three-fold responsibility in operating the permit system, conducting a county-wide inventory of all emission sources, and conducting special studies. This section is composed of registered, professional mechanical and chemical engineers who review plans and specifications for proposed installation or alteration of fuel-burning equipment or industrial process equipment that will be needed to bring those sources into compliance.

An installation permit is issued by the Engineering staff when they have determined that the proposed equipment will permit compliance with the Regulations. A final Certificate of Operation is awarded only when the completed installation has been demonstrated to operate in compliance with the emissions limitations in the Regulations. The operation is subject to an annual review and re-certification, and the certificate may be revoked at any time if emissions are not in continuing compliance with the regulations.

Another major task the Engineering Section performs is a County-wide inventory of all sources of air pollution, including the various types and strengths of emissions from each source Information from the public utilities is used to further identify the smaller sources. The inventory is being conducted in square-mile grids with all sources and streets listed for further correlation with field inspection reports.

The third major activity of the Engineering Section consists of special studies and issuance of guidelines of good practice. The Engineers prepare studies and reports concerning new equipment, control devices, and processes planned for the future. The reports are considered vital in keeping the Division abreast of the science and technology of air pollution control. This new information is also used to prepare recommendations to the Enforcement and Technical Services sections to offer guidelines of good practice for various types of processes and equipment that will aid and assist plant engineers, managers and owners, as well as other government agencies concerned with pollution control.

The Technical Services Section is composed of engineers, chemists, and technicians who are responsible for stack-sampling tests, source-monitoring studies and operation and maintenance of the Division's vast assortment of stationary and mobile air-monitoring equipment.

Typical examples of the Technical Services activities are: (1) monitoring of air quality in the vicinity of a major pollution source before and after installation of control equipment; (2) measuring pollution levels along expressways and busy surface streets; and (3) determining the chemical and mineral composition of dustfall and suspended particulates in various communities in the County.

The section is installing an advanced and sophisticated automatic, telemetered 13-station air monitoring network. These stations will continuously report levels of carbon monoxide, sulfur dioxide, hydrocarbons, nitrogen dioxide, total oxidants, and suspended particulates. Some stations will also report wind speed and wind direction.

The Administrative Services Section performs many of the normal supportive office functions such as clerical services, accounting and payroll, personnel services, employment, purchasing and invoicing. In addition, the Section performs collateral tasks such as internal-external communication, planning and scheduling, providing statistical information, systemizing office routines, and eliminating superfluous paperwork and activities.

The Public Information office informs the public of the various functions and activities of the Division and its personnel. This communication is accomplished through mass media - newspapers, radio, television, and magazines - with feature articles and news stories. Feature articles deal with the daily business of the Division and are prepared in such a manner that the media can use the material at any time. Current news stories, because of their timely nature, are prepared for immediate news coverage, and include items such as court actions, possible emergency situations, or announcements of new control programs. The office also prepares general information pamphlets describing air pollution, and its sources, effects, and control problems. The pamphlets are sent out singly or in quantity as they are requested. They are also used in connection with speaking engagements related to educational programs in schools.

A summary of Wayne County control agency operations is given in Table 5-2.

Table 5-2. AGENCY OPERATING STATISTICS

Action	1969	1970 (first 6 months)
Complaints investigated	3,127	1,973
Violation notices issued	4,209	3,070
Court cases processed	61	74
Commercial and industrial installation permits issued	355	366
Domestic incinerator installation permits issued	975	612
Total field inspections	28,629	18,069

6. CONTROL TECHNOLOGY

6.1 INTRODUCTION

The Air Quality Section (Section 2) of this document presents the amounts of air pollutants emitted into the atmosphere in the study area. This section discusses the means by which these emissions can be reduced.

It should be noted that, because of differences within individual plants, the techniques outlined may have to be modified for individual cases or other methods used to achieve the desired results.

No attempt has been made to deal with each individual source in the survey area; rather major sources have been highlighted in an attempt to indicate possible emission reductions. It is the responsibility of the regulatory agencies to work out detailed control programs for the individual sources. Since the completion of the 1967 emission inventory, many individual control programs have been implemented, resulting in a considerable reduction of atmospheric emissions.

6.2 POWER PLANTS (UTILITIES)

Steam-electric power plants and steam heating plants are the largest source of sulfur dioxide and the second largest source of particulate matter in the study area. These plants at the present time are all coal-fired.[1]

6.2.1 Particulate Emissions and Controls

The degree to which particulate emissions are controlled at the various power plants in the area varies from zero to more than 98 percent. Amount of coal fired at each plant, estimated collection efficiency, and estimated emissions are given in Table 6-1.

Additional control equipment has been and is being installed at several power plants, and some existing control units are being upgraded. Some coal-fired boilers have since been modified to burn natural gas and oil. Table 6-2 lists the control measures announced by the firms and the reduction in particulate emissions that will result. For example, there is only one Canadian power plant in the study area, the J. Clark Keith plant located in Windsor. Present plans call for this plant to be reduced to a peaking operation when new, large, and more efficient generating stations being constructed in Ontario become operative.

The feasibility of controlling coal-fired power plant particulate emissions with electrostatic precipitators of better than 99 percent efficiency is now well established. Some of the existing collectors are being upgraded to 99.6 percent efficiency. Table 6-3 lists the further reduction in particulate emissions that could be achieved if all the power plants not now equipped with collectors of better than 99 percent efficiency were so equipped. This does not include the plants for

Table 6-1. POWER PLANT PARTICULATE EMISSIONS

Plant	Type firing	Coal fired, tons/yr	Collector efficiency, %	Particulate emissions, tons/yr
Conners Creek L.P.	Underfeed, flyash reinjection	719,000	80[a]	11,200
Conners Creek H.P.	Pulverized	905,000	94[a]	3,600
Delray	Underfeed	888,000	80[a]	3,470
River Rouge	Pulverized	1,413,000	95[a]	6,000
River Rouge	Pulverized	658,000	97.6[b]	1,340
Trenton Channel L.P.	Pulverized	530,000	95[b]	2,430
Trenton Channel H.P.	Pulverized	797,000	98[b]	1,465
Pennsalt	Pulverized	167,300	80[a]	3,300
Wyandotte, North	Underfeed	70,000	None	1,920
Wyandotte, North	Pulverized	84,000	None	7,860
Wyandotte, North	Pulverized	253,000	80[a]	4,730
Wyandotte, South	Underfeed	205,800	None	5,770
Marysville	Underfeed	249,000	None	7,460
Marysville	Pulverized	464,000	95[c]	2,360
Port Huron Paper	Pulverized	30,900	80[c]	542
St. Clair	Pulverized	1,952,000	97.5[c]	5,380
St. Clair	Pulverized	920,000	97.9[b]	2,140
St. Clair	Cyclone	799,300	89.5[b]	1,093
Beacon St. H.P.	Underfeed	132,000	85[a]	361
Beacon St. H.P.	Underfeed	142,400	None	2,590
Congress St. H.P.	Underfeed	31,200	None	566
Willis Ave. H.P.	Underfeed	12,700	90[a]	23
Willis Ave. H.P.	Underfeed	63,500	None	1,160
Boulevard H.P.	Underfeed	5,200	None	75
Detroit Public L., Mistersky	Pulverized	261,000	80	2,590
Detroit Public L., Schrenk	Underfeed	13,030	0	353
Detroit Public L., Kiefer	Underfeed	8,595	0	232
Wyandotte Municipal	Underfeed	70,000	87	534
J. Clark Keith, Windsor	Pulverized	397,000	97	695
Total		12,242,000		81,239

[a] Estimated by Wayne County.

[b] Data from Federal Power Commission Air Quality Control Questionnaire for 1967.

[c] Estimated by Michigan State Health Department.

Table 6-2. SCHEDULED POWER PLANT CONTROL IMPROVEMENTS

Plant	Planned control measures	Emission reduction, tons/yr
Conners Creek L.P.	Supplementary gas and new mechanical collectors	10,500
Trenton Channel L.P.	Supplementary gas	2,000
Trenton Channel H.P.	Upgrade electrostatic precipitators (ESP's) to 99.6%	1,170
Pennsalt	Add ESP's of 99.6%	3,200
Wyandotte, North	Convert underfeed stokers and one pulverized unit to gas	9,780
Wyandotte, North	Add ESP's of 99.6% to pulverized units	4,635
Beacon St., Heating Plant	Add mechanical collectors	2,200
Wyandotte Municipal	Convert to gas turbine	534
Port Huron Paper	Convert to gas	542
Total		34,561

which upgrading plans have been announced. Although it is possible to attain 99 percent collection efficiency for particles emitted from power plants, it has been shown that the sulfur content of the coal has an influence on the efficiency. Design of the precipitator must take this into account. Higher temperatures tend to counteract the decrease in efficiency resulting from a sulfur content less than about 1.7 percent. Placement of the precipitator ahead of the air preheater may be necessary. An increase in the amount of collector surface area may also be necessary.

6.2.2 Sulfur Dioxide Emissions

Sulfur dioxide emitted from power plants in the Detroit – Port Huron area comprises 72 percent of the total sulfur dioxide emissions, 571,000 tons per year.

Sulfur dioxide emissions can be reduced by two general methods: (1) use of low-sulfur fuels, and (2) flue-gas desulfurization.[2] Possible low-sulfur fuels include natural gas, distillate oil, residual oil, and coal. Several flue-gas desulfurization methods have possible applicability.

Natural gas, as used, is always very low in sulfur. Where it is available in adequate quantities, it is used as power plant fuel. A few plants in the study area are converting to gas, but supplies are not adequate to furnish the bulk of the power plant fuel.

Distillate oil is nearly always low in sulfur, but it is never used as the primary fuel for a power plant because it is too expensive. It is sometimes used, rather, as the standby fuel for plants on interruptible gas service.

Residual oil is being used as a power plant fuel in a few plants in the Eastern United States and is being seriously considered as the primary fuel for public utilities in the Midwestern States. Much of it is imported and is low in sulfur content.

Table 6-3. REDUCTION IN POWER PLANT PARTICULATE EMISSIONS IF ALL COLLECTORS ARE UPGRADED TO 99 PERCENT EFFICIENCY[a]

Plant	Present efficiency, %	Present emissions, tons/yr	Emissions at 99 percent efficiency, tons/yr	Emission reduction, tons/yr
Conners Creek H.P.	94	3,600	600	3,000
Delray	80	3,470	170	3,300
Wyandotte, South	0	5,770	60	5,710
Marysville	0	7,460	75	7,385
Marysville	95	2,360	470	1,890
St. Clair	97.5	5,380	2,150	2,230
St. Clair	97.9	2,140	1,020	1,120
St. Clair	89.5	1,093	104	990
Beacon St. H.P.	90	400	40	360
Congress St. H.P.	0	566	6	560
Willis Ave. H.P.	0	1,160	12	1,148
Boulevard H.P.	0	75	1	74
Detroit Public L., Mistersky	80	2,590	259	2,331
Detroit Public L., Schrenk	0	352	4	348
Detroit Public L., Kiefer	0	232	2	230
River Rouge	95	6,000	1,200	4,800
River Rouge	97.6	1,340	560	780
J. Clark Keith	97	695	232	463
Total				36,719

[a] Excludes power plant collectors given in Table 6-2.

Low-sulfur coal offers a possible solution and is discussed in the following section.

6.2.3 Control of Sulfur Dioxide Emissions

6.2.3.1 Low-Sulfur Coal - The sulfur content of the coal used by the power plants varies from 0.75 to 4 percent. Several plants burn coal of around 1 percent sulfur. Table 6-4 lists present sulfur dioxide emissions and the reduction that could be obtained if only 1 percent sulfur coal were used. The reduction in sulfur dioxide emissions would be 61 percent.

The supply of naturally occurring low-sulfur coal could be augmented by additional coal preparation plants. Pyritic sulfur can be removed from coal by mechanical means such as crushing and gravity separation. Such methods can remove only part of the sulfur, but they provide a potential means for significantly reducing the sulfur dioxide emitted from power plants.

Table 6-4. REDUCTION IN POWER PLANT SULFUR DIOXIDE EMISSIONS MADE BY SWITCHING TO 1-PERCENT-SULFUR-COAL

Plant	Coal fired[a] tons/yr	Sulfur, %	Sulfur dioxide emissions, tons/yr		
			Present percent S coal	1-percent S coal	Reduction
Conners Creek, L.P.	719,000	1.3	17,800	13,700	4,100
Conners Creek, H.P.	905,000	3.1	53,500	17,200	53,300
Delray	888,000	1.3	21,900	16,880	5,020
River Rouge	2,071,000	3.6	141,500	39,300	102,200
Trenton Channel	530,000	1.1	11,100	10,100	1,000
Trenton Channel	797,000	2.3	34,800	15,100	19,700
Pennsalt	167,300	1.2	3,800	3,170	640
Wyandotte N.	407,300	1.4	10,800	7,720	3,110
Wyandotte S.	205,800	1.3	5,100	3,950	1,130
Marysville	712,800	2.6	35,200	13,600	21,600
St. Clair	3,671,000	3.3	230,000	69,700	160,300
Mistersky	261,000	1.0	4,960	4,960	0
J. Clark Keith	397,000	2.0	15,840	7,920	7,920
Others	510,000	1.0	9,700	9,700	0
Total	12,242,000		595,700	233,100	362,600

[a] Data from Federal Power Commission Air Quality Control Questionnaire for 1967.

The National Air Pollution Control Administration has funded several studies on feasibility of removing pyritic sulfur from coal. These studies have pointed up a lack of sufficient data on sulfur distribution and characteristics in a given coal seam, the washability of a given coal seam, and the capabilities of present cleaning operations. The United States National Air Pollution Control Administration (NAPCA) is currently funding research programs to determine: (1) efficiency and applicability of available coal-cleaning methods for pyrite separation; (2) available sources of high-sulfur coals capable of being desulfurized; and (3) costs and technical limitations of proven technology for converting the refuse from coal cleaning into useful products.

Although the use of low-sulfur fuels is a possible solution to the reduction in sulfur dioxide emissions, such fuels are in extremely short supply and it is doubtful if a continuing supply could be obtained that would meet the total demand of all the power plants in the study area.

As an interim measure, it may be possible to utilize low-sulfur fuels during periods of adverse meteorological conditions.

Because of the short supply of all power plant fuels, costs have been increasing almost daily and it is not possible, therefore, to predict with any degree of accuracy the cost of substituting low-sulfur fuels.

6.2.3.2 Flue Gas Desulfurization - A number of processes for removing sulfur dioxide from flue gases are currently being developed. The three most promising are: injection of limestone or dolomite, catalytic oxidation, and alkalized-alumina sorption.[2] The injected-limestone process is currently being tested on boilers in several locations in the United States. The alkalized-alumina and catalytic-oxidation processes are being studied, and other processes that show potential for improved economy and control are being developed.

6.2.3.2.1 Alkalized-alumina sorption. The alkalized-alumina process uses a dry metal oxide to contact and absorb the SO_2 in a gas stream. Solid sorbent in the form of spheres of sodium aluminate is activated at 1200° F to form high-porosity, high-surface-area sorbent, which reacts with SO_2 to form sodium sulfate. The spent sorbent is heated to 1200° F and enters a regenerator where it contacts a reducing gas, primarily H_2, CO, and CO_2 formed from re-forming of fuel oil or natural gas. The sodium aluminate is regenerated, and the sulfur compounds converted to hydrogen sulfide. A conventional Clause unit converts the H_2S to elemental sulfur.

Advantages of this process are: (1) it produces a valuable by-product, sulfur, and (2) the stack gases are released at a high enough temperature (250° to 300° F) to maintain buoyancy of the stack effluent. Disadvantages are: (1) sorbent make-up costs are high because of attrition,[3] and (2) the process is most applicable to new power stations. Capital costs are high, estimated to be $10.64 per kilowatt to control an 800-megawatt coal-fired plant.

6.2.3.2.2 Catalytic oxidation. The catalytic-oxidation process is an adaption of the contact catalytic process used in the manufacture of sulfuric acid. Sulfur dioxide is oxidized to sulfur trioxide by passing the flue gases over a vanadium pentoxide catalyst. The SO_3 then combines with water vapor in the flue gas to form sulfuric acid. Subsequent cooling condenses the acid. A high-efficiency electrostatic precipitator is used to remove particulate matter before the gas enters the catalyst bed at a temperature of 800° to 850° F. Cooling in the air preheater and economizer causes sulfuric acid to condense. The acid is then collected in an absorbing column and a mist eliminator.

Some of the disadvantages are: (1) the need for expensive corrosion-resistant construction materials in the cooler section, and (2) the process is difficult to apply to older plants because of the problems of tapping existing flue-gas streams at a point where required temperatures exist.

Estimated installation cost for this process is $20 to $30 per kilowatt above that of a new conventional power station. The operating costs for an 800-megawatt plant have been estimated to be $1.75 per ton of coal burned, without credit for the acid produced. If the 78 percent acid can be sold for $10 per ton, costs can be reduced to $1.06 per ton of coal fired.

6.2.3.2.3 Limestone injection. Limestone-based injection processes produce no useful by-product, but investment and operating costs are less. Two basic injected-limestone processes are currently being investigated, a dry process and a wet process.

In the dry process,[4] pulverized limestone or dolomite is injected into a high-temperature zone of the furnace where it is calcined to the reactive oxides, CaO and

MgO. The reaction of the additive with SO_2 and oxygen at temperatures above 1200° F forms gypsum ($CaSO_4$). Sulfates, unreacted lime, and flyash are removed by conventional particle collectors. Additional electrostatic precipitator capacity may be required, however, to maintain a given collection efficiency.

In the wet process, limestone is injected into the combustion zone of a boiler where it is calcined to reactive lime. The lime and flyash are collected by a scrubber where the calcined limestone forms a slurry of reactive milk-of-lime, which reacts with the SO_2 in flue gas to form sulfite and sulfate salts. The spent scrubber liquor and reaction products are allowed to settle. Ash and reacted lime are removal for disposal. Scrubber liquor is recycled to reduce water requirements and avoid water pollution.

This process for SO_2 control has been installed for use on three full-scale power plant boilers in the 125- to 420-megawatt range. Conceptual design and economic studies conducted by TVA under NAPCA contract indicate that the capital investment for the dry limestone injection process for an 800-megawatt power plant would be about \$3,000,000 and the net operating cost when removing 40 to 60 percent of the SO_2 would be about \$0.73 per ton of coal fired.[5] These figures assume limestone delivered at \$2.00 per ton, and 200 percent stoichiometric addition of limestone. Similar estimates of the capital and operating costs of the limestone scrubbing process indicate that capital costs would be \$4,000,000 and operating costs would be \$0.94 per ton of coal fired.[5] Operating cost estimates by the vendor range from \$0.35 to \$0.50 per ton of coal (\$0.015 to \$0.02 per million Btu).[6]

6.3 INDUSTRIAL AND COMMERCIAL FUEL CONSUMPTION

The fuels used by industrial, commercial, and governmental installations are given in Table 6-5, with the atmospheric emissions from these sources. This does not include coal used for the production of metallurgical coke or coal used in the production of lime and cement. Emissions from these sources are listed under industrial process emissions.

Table 6-5. INDUSTRIAL AND COMMERCIAL FUEL CONSUMPTION

Fuel	Consumption	Emissions, tons/yr		
		Particulates	Sulfur oxides	Nitrogen oxides
Bituminous coal	5,857,000 tons	105,704	176,376	53,347
Distillate oil	350,300,000 gal	2,640	8,769	12,506
Residual oil	298,634,000 gal	3,408	40,405	10,556
Natural gas	233,656 x $10^6 ft^3$	2,063	40	21,258

From Table 6-5, it can be seen that, of the fuels consumed, coal is the major source of both particulate and sulfur oxide emissions.

6.3.1 Boiler Controls

Many of the larger industrial or commercial boilers have multiple cyclone collectors for reducing particulate emissions. Only a few of the largest units are equipped with electrostatic precipitators. To achieve a substantial reduction of emissions from this category of sources, the use of electrostatic precipitators should be extended.

Multiple cyclone collectors consist of small-diameter cyclones installed in parallel in an integral housing. Nine-inch diameter cyclones are widely used. Units can be assembled to control any sized boiler. Collection efficiency for fly-ash ranges from 75 to 90 percent.

Electrostatic precipitators for large boilers are custom-designed and field-assembled. Until recently their use has been restricted to large boilers but packaged, factory-assembled units are now available in sizes to control medium-sized industrial and commercial boilers. Consequently, highly efficient collectors are available at moderate cost for all but the smallest boilers. The collection efficiency of electrostatic precipitators ranges from 95 to better than 99 percent.

In the practical application of control equipment to satisfy the restrictive emission requirements in use in the study area, it has been found acceptable to use multiclone collectors for non-pulverized coal boiler systems. Pulverized coal boilers require the application of electrostatic precipitators. The larger stoker-fired systems in the range of 300,000 pounds of steam per hour or greater justify consideration of electrostatic precipitators as control measures. The reductions in particulate emissions that could be achieved by these measures are shown in Table 6-6. A reduction of 48,726 tons per year is possible from the sources listed.

6.3.2 Sulfur Dioxide Emissions from Industrial and Commercial Boilers

Sulfur dioxide emissions from boilers can be reduced by fuel substitution and by flue-gas desulfurization. Possible fuel substitutes are low-sulfur coal, natural gas, distillate oil, and residual oil.

The coal used in industrial and commercial boilers varies from 0.75 to 4.0 percent. If coal of 1.0 percent sulfur or less were used exclusively, sulfur dioxide emissions would be reduced by 50,000 tons per year, or 34 percent of the emissions from this category.

Natural gas has a negligible sulfur content and is being used in increasing quantities in this area for industrial and commercial applications; however, evaluating the prospects for significantly increasing the present supply is beyond the scope of this study.

Distillate oil, usually low in sulfur, is used by a considerable number of industrial and commercial firms in this area. Increased use of this fuel could significantly reduce sulfur dioxide emissions. Those who require large amounts of fuel, however, find its cost to be uneconomical compared with that of coal.

Some of the residual oil used in this area contains an average of 0.8 percent sulfur; however, about two-thirds of the amount used averages 2.2 percent sulfur. If it were possible to substitute residual oil of 1.0 percent sulfur for all of the coal used in this category, a reduction of 68,000 tons of sulfur dioxide, or 46 percent, would be achieved. Although fuel substitution might be a possible means of reducing SO_2 emissions, the short supply of residual oil precludes this course of action at the present time.

Table 6-6. PARTICULATE EMISSIONS FROM COAL FIRING BY INDUSTRIAL, COMMERCIAL, AND GOVERNMENTAL INSTALLATIONS

Source	Type firing[a]	Coal fired, tons/yr	Collector		Emissions, tons/yr	Projected control, %	Emission reduction, tons/yr
			Type	Efficiency, %			
Chrysler, Trenton Engine	SS	31,064	C[b]	92	116	-	-
Ford, Wayne Assembly	OS	26,566	None	0	530	80	424
Scott Paper Co.	UF	60,000	None	0	1,050	80	840
Scott Paper Co.	SS	48,000	C	80	437	-	-
Ford, Steel Division	P	679,230	C	85	4,000	99	3,730
Fisher Body, Fleetwood	SS	19,862	C	85	102	-	-
Allied Chemical, Semet-Solvay	OS	17,400 (Coke breeze)	None	0	222	80	180
Allied Chemical, Detroit Alkali	P	120,000	C	70	2,592	97	2,330
Parke, Davis and Co.	UF	1,907	None	0	29	-	0
Parke, Davis and Co.	P	17,033	C	85	125	-	-
U.S. Rubber	P	130,000	C	74	1,466	97	1,300
Chevrolet, Livonia	SS	50,148	C	90.5	217	-	-
Chrysler, Jefferson Ave.	UF	72,000	None	0	1,013	80	810
Chrysler, Mack Ave.	UF	23,030	None	0	633	80	507
Chevrolet, Detroit Forge	P	165,068	C	84	2,273	98	1,990
Chrysler, Hamtramck	UF	110,000	None	0	1,925	80	1,540
Fred Sanders Co.	OS	4,770	None	0	155	80	124
Chrysler, Detroit Forge	UF	35,100	None	0	878	-	-
Chrysler, Detroit Forge	P	27,500	C	50	1,168	80	1,090
Chrysler, Detroit Forge	SS	40,400	C	92	210	-	-
Chrysler, 8 Mile Stamping	OS	30,000	None	0	750	80	600
Levy Slag	SS	15,000	None	0	672	80	538
Pontiac	UF	8,537	None	0	141	80	113
Chrysler, Warren Truck	UF	50,000	None	0	875	80	700

Table 6-6 (continued). PARTICULATE EMISSIONS FROM COAL FIRING BY INDUSTRIAL, COMMERCIAL, AND GOVERNMENTAL INSTALLATIONS

Source	Type firing[a]	Coal fired, tons/yr	Collector		Emissions, tons/yr	Projected control, %	Emission reduction, tons/yr
			Type	Efficiency, %			
Chrysler, Sterling	SS	26,800	C	92	101	-	0
LTV	SS	20,000	C	80	196	-	-
Ford, Sterling	SS	48,610	C	92	190	-	-
Ford, Utica	UF	11,040	None	0	138	80	110
Diamond Salt	UF	4,500	C	85.5	830	97	660
Diamond Salt	P	64,500	C	85.5	-	-	-
Chrysler, Marysville	OS	10,332	None	0	186	80	144
Grand Trunk Western Railroad	OS	4,000	None	0	234	80	185
Dunn Paper Co.	P	11,075	None	0	483	97	468
Wayne County General Hospital	SS	35,000	C	80	345	-	-
Detroit Army Arsenal	SS	31,368	None	0	2,040	80	1,632
Selfridge Air Force Base	SS	10,575	None	0	621	80	500
Army Missile	SS	21,000	None	0	820	80	655
Allied Chemical, Ontario	P and SS	180,030	C	0-70	4,412	97	4,150
Ford, Windsor, Ontario	P	130,000	C	0-85	5,700	97	5,450
Polymer, Ontario	P	590,000	C	70	18,240	99	15,650
Dow Chemical, Ontario	P	180,000	ESP[c]	85	1,857	97	1,500
Dominion Forge, Ontario	SS	11,500	C	65	174	80	36
Hiram Walker, Ontario	P	60,000	C	75	840	97	770
Total		3,257,697			59,108		48,726

[a] SS = Spreader stoker; UF = underfeed; P = pulverized, and OS = other stoker.

[b] Cyclone.

[c] Electrostatic precipitator.

The flue-gas desulfurization methods discussed for power plants could conceivably be used on industrial and commercial boilers. The alkalized-alumina and catalytic-oxidation processes require such a high capital investment, however, that it is unlikely they could be feasible. The dry dolomite process would be feasible from the cost standpoint, but further development would be required to determine if it is technically feasible. The wet dolomite process also requires further investigation to determine if it is applicable to industrial and commercial boilers.

Scrubbers have been used to remove particulate matter from the flue gas of small power plants and industrial boilers. Similar scrubbers have also been used, with a caustic solution, to remove sulfur dioxide from flue gases that are subsequently processed into liquid carbon dioxide and dry ice. It has been proposed that such scrubbers, with a soda ash solution or lime slurry, be used to remove SO_2 from industrial boiler flue gases.[7] Cost analyses show that the installation of such a scrubber, when compared with the use of low-sulfur coal for a 200,000 pound-per-hour boiler, would result in a net saving. Efficiencies of up to 99 percent could be attained in removing SO_2 and about the same for particulate matter. The suggestion has been made that about 25 percent of the flue gas should bypass the scrubber and be added to the stack to maintain buoyancy and prevent the formation of steam plumes. This of course would result in about a 75 percent reduction efficiency for both particulates and SO_2.

6.4 RESIDENTIAL FUEL CONSUMPTION

The fuels used for residential heating are given in Table 6-7, with the atmospheric emissions from these sources.

Table 6-7. RESIDENTIAL FUEL CONSUMPTION[a]

		Emissions, tons/yr		
Fuel	Consumption	Particulates	Sulfur oxides	Nitrogen oxides
Anthracite coal	64,240 tons/yr	643	578	257
Bituminous coal	655,600 tons/yr	6,533	13,000	2,672
Distillate oil	346,880,000 gal/yr	1,328	2,657	1,993
Residual oil	2,045,000 gal/yr	8	123	74
Natural gas	121,576 x $10^6 ft^3$/yr	1,095	24	7,050

[a] Includes apartment buildings.

From the table it can be seen that residential fuel consumption is not a large source of any pollutants. Switching from bituminous coal to natural gas or distillate oil could, however, achieve a slight reduction in particulates and sulfur oxides. In the Canadian study area, almost no coal is used for residential heating.

6.5 INDUSTRIAL PROCESSES

Industrial processes produce the largest amount of particulate emission of any category in the area, 26.9 percent of the total.

6.5.1 Steel Mills

6.5.1.1 Principal Sources of Emissions - Principal sources of emissions from steel mills are: blast furnaces, basic oxygen furnaces, open hearth furnaces, sintering plants, coke ovens, and scarfing machines. Some of these operations are well controlled, others are partly controlled, and some are uncontrolled.

6.5.1.1.1 Blast furnaces. Blast furnaces are controlled by high-energy scrubbers or electrostatic precipitators. Since the carbon monoxide in blast-furnace gas makes it valuable as a fuel, the degree of control—because control is economical—is always good.

6.5.1.1.2 Basic oxygen furnaces. Basic oxygen furnaces emit voluminous quantities of iron oxide fume. All such furnaces in the United States have been provided with control systems containing high-energy scrubbers or electrostatic precipitators. Many of these systems have achieved efficiencies of 99 percent.

6.5.1.1.3 Open hearth furnaces. Open hearth furnaces were operated mainly without controls in the years prior to the introduction of the oxygen-lancing technique. Oxygen lancing produces such copious emissions that controls have been required in most areas where this technique is practiced. Electrostatic precipitators, baghouses, and venturi scrubbers have provided successful control systems for these operations.

6.5.1.1.4 Sintering plants. Sintering plants process ore fines and collected iron oxide dust to produce clinkers or agglomerates that can be charged to a blast furnace. Cyclones and medium-efficiency scrubbers provide a moderate degree of control, but high-energy scrubbers or electrostatic precipitators are required to provide truly adequate control.

6.5.1.1.5 Scarfing machines. Scarfing machines contain oxy-acetylene torches that burn off the oxide coating from billets and slabs prior to their entry into rolling machines. Copious emissions of iron oxide fumes are produced. Adequate hooding and exhaust ventilation and a high-efficiency collector such as an electrostatic precipitator or venturi scrubber are required to control these emissions adequately.

6.5.1.1.6 Coke ovens. Coke ovens emit visible smoke and particulate matter during the following operations: charging of coal into the ovens, leakage during carbonization, and discharge of coke from the ovens. Improvements in both coke-oven design and operating practices can reduce emissions.

One important improvement over older plants is the installation of steam-jet aspirators in the gas-collecting elbows to aspirate gases from the interior of the oven during charging. Some smoke may still escape from the opposite end due to the distance the gases must travel. This effect can be minimized by installing two gas-collecting mains with an aspirator at each end of the oven.

Any arrangements that reduce the time required for transfer of the coal charge from larry hopper to oven interior also reduce the amount of smoke that escapes. Several mechanical devices are available for this purpose, including hopper vibrators in conjunction with smooth stainless-steel liners, cylindrical hoppers and bottom turn-table feeders, and a screw-feed mechanism. With these devices, oil-sprayed coal moves out of the larry-car hoppers with much greater facility, thus reducing the time required for charging.

Another device, consisting of drop sleeves and shear gates, provides an enclosure between the hopper of the larry car and the top of the charging hole to prevent the escape of gases from the charging hole.

A smoke seal box surrounding the leveling-bar opening can prevent emissions from this opening during the leveling operation.

6.5.1.2 Area Steel Mill Emissions and Controls – There are three integrated steel mills in the study area, all located in the United States: Great Lakes Steel, Ford Motor Company's steel plant, and McClouth Steel.

The present emissions and the reductions possible with good controls are listed for each of the mills in Tables 6-8, 6-9, and 6-10.

Table 6-8. GREAT LAKES STEEL PARTICULATE EMISSIONS

Operation	Present controls		Emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
	Type	Efficiency			
Blast furnace	ESP[a]	99.6	1,584	99.5	0
Basic oxygen furnaces	ESP	95	3,430	99	2,800
Open hearth furnaces	None	0	9,065	98	8,800
Sintering plant	Cyclone	75	4,550	98	4,190
Clinker cooler	Scrubber	75	5,000	98	4,600
Scarfing machine	None	0	1,000	95	950
Coke plant	None		2,660	65	1,730
Total			27,289		23,070

[a] Electrostatic precipitator.

Great Lakes Steel plans to install two new basic oxygen furnaces in mid-1970 and close down the open hearth furnaces. A new coke battery is planned for 1970 to replace one of the present batteries. Maintenance is to be accelerated on others. An electrostatic precipitator is to be installed in late 1970 to control the sinter plant.

McClouth plans to install a new and larger basic oxygen furnace (BOF) to replace two presently inadequately controlled BOF's.

Since the emission survey, Ford has discontinued the use of the sintering plant.

6.5.2 Cement Plants

There are four cement producers in the United States study area: Wyandotte Chemicals Corporation, South Works, and three American Cement Corporation

Table 6-9. McCLOUTH STEEL PARTICULATE EMISSIONS

Operation	Present controls		Emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
	Type	Efficiency, %			
Blast furnace	ESP[a]	99.8	300	99.5	0
Basic oxygen furnaces	Scrubber	84	4,750	99	4,450
Electric furnaces	Scrubber	49	505	99	495
Sintering plant	ESP	98	550	99	275
Clinker cooler	Scrubber high-energy	99	117	99	0
Scarfing machines	Scrubber high-energy	99	150	99	0
Total			6,372		5,220

[a] Electrostatic precipitator.

Table 6-10. FORD STEEL PARTICULATE EMISSIONS

Operation	Present controls		Emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
	Type	Efficiency, %			
Blast furnace	ESP	99.5	600	99.5	0
Basic oxygen	ESP	99	400	99	0
Coke ovens	None	—	800	65	520
Sinter plant	Cyclone	90	875	99	785
Total			2,675		1,305

Plants, Peerless Division, located respectively on Jefferson Street and Brennan Avenue in Detroit, and on State Street in Port Huron.

Sources of particulate emissions in the production of cement are: crushing, grinding, and blending of raw materials; clinker production; and finish grinding and packaging. The amount of dust produced during crushing depends on the moisture content of the raw materials. The dust produced by crushing and conveying the raw material is usually collected by centrifugal collectors or cloth filters. If the grinding and blending are done by the wet process, then there are no emissions from these steps. Dry grinding and blending, however, does produce dust. This dust is usually entrained in a closed system and collected on a cloth filter. Clinker production includes both kiln burning and clinker cooling and is the largest source of pollutants. The kiln is usually on a closed system with a cyclone and electrostatic precipitator, cyclone and bag filter, or just a bag filter to collect the dust from the system. Most of the dust is returned to the kiln; however, some high-alkali dust must be discarded to produce a low-alkali cement. The final grinding and packaging dusts can be collected on a cloth filter.

Wyandotte Chemicals Corporation, South Works, presently has about 96.3 percent control efficiency with a combination of a multicyclone and electrostatic precipitator. The efficiency of the precipitator can be raised to 99 percent, reducing the emissions by 891 tons per year as shown in Table 6-11. The Jefferson Street Plant of the American Cement Corporation, Peerless Division, is using electrostatic precipitators with 95.5 percent efficiency to control emissions. This control efficiency can be elevated to 99 percent, thereby reducing emissions by 770 tons per year. The Peerless Brennan Avenue Plant also uses electrostatic precipitators, but these ESP's have an efficiency of 96.7 percent. An increase to 99 percent efficiency would reduce emissions at this plant by 892 tons per year. The Peerless Port Huron Plant uses an electrostatic precipitator with 92 percent efficiency to control emissions. Upgrading this collector to 99 percent efficiency would reduce emissions by 1,243 tons per year. (These data are presented in Table 6-4.)

Table 6-11. EMISSIONS FROM CEMENT MANUFACTURING

Company	Present controls		Emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
	Type	Efficiency, %			
Wyandotte - South	ESP	96.3	1,211	99	891
Peerless - Jefferson	ESP	95.5	990	99	770
Peerless - Brennan	ESP	96.7	1,280	99	892
Peerless - Port Huron	ESP	92.0	1,420	99	1,243
Total			4,901		3,796

6.5.3 Lime Plants

There are three lime producers in the United States portion of the study area: Marblehead Lime Company, Division of General Dynamics Corporation; Wyandotte Chemicals Corporation, South Works; and Wyandotte Chemicals Corporation, North Works. The first two companies control better than 99 percent of their emissions; the third company, which has a vertical kiln, has no control but reports emissions that are less than either of the first two. There seems to be no reduction possible for particulate emissions from lime production in the area.

6.5.4 Fertilizer Plants

There is one fertilizer complex in the study area, Canadian Industries Limited (CIL), in Courtright, Ontario. It contains a 1,000-ton-per-day anhydrous ammonia plant, and satellite plants for the production of nitric acid, ammonium nitrate, nitrogen solutions, urea, phosphoric acid, and ammonium phosphates.

Residual oil, Bunker No. 6, is used as fuel in the boiler house. Because the boiler stacks are relatively low (75 feet), SO_2 emissions exceed the permissible limit. Use of lower-sulfur-content fuel or higher stacks would reduce the ground-level concentration to below 0.3 ppm SO_2.

There are also particles emitted from three plant stacks discharging ammonium nitrate and ammonium phosphate. Ammonium nitrate is very soluble and can be removed by a wet scrubber. Ammonium phosphate is recovered by a cyclone-type scrubber that discharges into the ammonia recovery towers. Efficiency is 98 percent. Emissions are shown in Table 6-12.

Table 6-12. EMISSIONS FROM CIL FERTILIZER PLANT

Material	Source	Emissions, tons/yr	Present collector	Efficiency, %	Potential efficiency, %	Possible reduction, tons/yr
SO_2	Boiler house	626	-	-	-	626 tons with gas
Ammonium nitrate	Prilling	330	Scrubber	95	98	200
Ammonium nitrate	Dryer	65	Venturi scrubber	98	98	-
Ammonium phosphate	Dryer	330	Cyclone scrubber	98	98	-

6.5.5 Grain Handling and Processing Companies

The study area has two grain handling and processing companies that emit particulate pollution. Fine grain particles are produced during the milling of grain or drying of alfalfa. The latter operation is seasonal in nature while the former is a 12-month operation.

Calvert of Canada emits approximately 430 tons per year of mainly grain particulates in its production of potable and industrial alcohols. All milling and drying operations are fitted with cyclones, and the milling operation is also fitted with a bag filter to catch particles smaller than 10 to 20 microns. Installation of bag filters on the remaining cyclones would reduce the existing particulate emissions to acceptable levels.

Greenmelk dehydrates alfalfa, emitting 320 tons per annum in the process. Cyclones are essentially low-efficiency collectors in the fine particulate range.

6.5.6 Sugar Companies

During the survey, a sugar-producing company, Canada and Dominion Sugar, reported the emission of 63 tons per year of particulate matter and 463 tons per year of sulfur oxides. The plant has since shut down its beet-processing operation.

6.5.7 Petroleum Refineries

Five petroleum refineries are located in the study area: Marathon Oil Company in Detroit; Mobil Oil Company in Trenton; and Shell Canada, Sun Oil, and Imperial Oil, all located south of Sarnia.

Petroleum refineries emit several different types of pollutants, including particles, hydrocarbons, sulfur oxides, and carbon monoxide. There are many points in the refining process at which one or more of these pollutants can be emitted. Refineries burn large amounts of residual fuel oil in boilers and process heaters. Oil consumption by refineries and the resulting emissions are included in Table 6-5 and discussed in Section 6.3. On the basis of the information provided by the companies, controls for the pollutants at several points in each plant are discussed.

Marathon Oil has a sulfur recovery plant that aids in controlling the sulfur dioxide emissions. In the recovery process hydrogen sulfide is absorbed from the sour-gas stream by a regenerative absorbent. After desorption, part of the hydrogen sulfide is combusted with air to form sulfur dioxide. Then the hydrogen sulfide and sulfur dioxide are reacted in one or more catalytic converters to form sulfur vapor; the vapor is then condensed to liquid sulfur. After passing through the last converter and condenser, the remaining hydrogen sulfide is combusted and released to the atmosphere as sulfur dioxide. Marathon has two converters with a combined efficiency of just over 89 percent. A third converter would increase the efficiency to 97 percent and reduce the sulfur dioxide emissions by 2,000 tons per year; that is, from 2,800 to 800 tons per year.

Imperial Oil, Shell Canada, and Mobile Oil also have sulfur recovery plants. Conversion efficiencies were not reported but are presumed to be equal to the industry average, about 93 percent.

All of the refineries operate catalytic-cracking units. Imperial, Marathon, and Shell have fluid catalytic-cracking units. Mobil and Sun Oil have moving-bed units. If average emission rates are assumed, the fluid units emit a total of 2,500 tons per year of catalyst dust. Electrostatic precipitators have been used to control such units and could reduce these emissions to 250 tons per year. At average emission rates, the two moving-bed units emit a total of 500 tons per year. High-efficiency cyclone collectors could reduce these emissions to 100 tons per year.

Since the survey was made, all Canadian refineries have installed carbon monoxide boilers, which necessitates the reduction of catalyst dust losses. This reduction in emissions ranges from 2 to 4 tons per day to less than 0.5 ton per day.

Marathon's fluid coker uses fluidized coke for heat transfer. Abrasion during the transport of the fluidized coke from the reactor to the regenerator creates some fine coke particles that are emitted to the atmosphere. This fine-particle coke can be collected either by high-efficiency scrubbing or by evaporative cooling and baghouse collection. Either of these methods will reduce the coker particulate emissions by 90 percent, from 1,800 to 180 tons per year.

Hydrocarbon emissions at all refineries can be reduced by improvements in waste water separators and process drains. All initial separator boxes should be enclosed to prevent excessive evaporation of hydrocarbons. All sewer junctions should also be covered and drains should have liquid seals. The waste-water separator tanks should be provided with floating-roof covers. These improvements, in conjunction with the use of good housekeeping practices to prevent spills, will reduce the hydrocarbon emissions. In addition, the use of floating-roof tanks, particularly on high R.V.P. materials will reduce hydrocarbon emissions considerably.

Carbon monoxide is controlled at both of the refineries in the United States that use carbon monoxide boilers (which utilize the carbon monoxide as fuel to provide heat for other parts of the refining process).

Imperial Oil and Sun Oil indicated emissions of approximately 55,000 tons per year and 8,300 tons per year, respectively, of carbon monoxide at the time of the survey; since that time, carbon monoxide boilers have been installed.

6.5.8 Chemical Plants

6.5.8.1 Sulfuric Acid Plants - There are four chemical companies with sulfuric acid plants in the area: Allied Chemical, W. R. Grace, E. I. DuPont, and Detroit Chemical Works.

Principal sources of emissions of sulfuric acid mist and sulfur dioxide are the exhaust stacks of the sulfuric acid plants. The mist is found in the gaseous effluent from the final absorbing tower, whereas the sulfur dioxide is the result of the incomplete conversion of sulfur dioxide to sulfur trioxide in the catalytic converters.

Sulfuric acid mist is controlled at a medium efficiency (50 percent) in only one plant by use of a mist eliminator of an older design. The other plants have no controls for sulfuric acid mist. New designs of mist eliminators claim efficiencies of 99 percent. The electrostatic precipitation of sulfuric acid mist has achieved efficiencies slightly greater than 99 percent. The cost of ESP control is considerably higher than that of demister control. Mist eliminators of newer design control adequately the sulfuric acid mist from absorbing towers.

The present emissions of sulfuric acid mist and the reductions possible with good controls are given in Table 6-13.

Table 6-13. SULFURIC ACID MIST EMISSIONS

Company	Present control		Emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
	Type	Efficiency, %			
Allied Chemical	None	0	85	99.0	84.16
W. R. Grace	-	-	-	-	-
Detroit Chemical Works	None	0	75	99.0	67.5
E. I. DuPont[a]	Mist eliminator	50	150	99.0	147.0
Total			310		298.16

[a] Ceased operations July 1968.

One plant reports a 95.0 percent conversion of sulfur dioxide to sulfur trioxide while 96.0 percent efficiencies are assumed for the other plants. The double contact process for manufacturing sulfuric acid has achieved a conversion efficiency of 99.5 percent. Several of these processes are operated in Europe and domestic installation is planned for one Eastern state. Stack gases have been scrubbed for removal of sulfur dioxide for many years at Trail, British Columbia, Canada. Installation of a stack scrubber to retain 95 percent of sulfur dioxide is expensive and often produces a by-product of little or no commercial value. Utilization of the double contact process provides substantial savings in raw material costs and gives good control of sulfur dioxide emissions as well.

The present emissions of sulfur dioxide and the reductions possible with good controls are given in Table 6-14.

Table 6-14. SULFUR DIOXIDE EMISSIONS

Company	Present control		Good control efficiency, %	Possible reduction, tons/yr
	Conversion efficiency, %	Emissions, tons/yr		
Allied Chemical	96.0	2,700	99.5	2,363
W. R. Grace	95.0	1,700	99.5	1,530
E. I. DuPont[a]	96.0	2,200	99.5	1,925
Total		6,600		5,818

[a] Plant shut down in July 1968.

6.5.8.2 Other Chemical Processes - Other chemical processes that emit pollutants are discussed below.

6.5.8.2.1 Talc drying. Champion Spark Plug Company has two operations that could feasibly be controlled. The first of these is the spray drying of talc. At the present time the dryer is not controlled and emits 92 tons of particles per year. The spray dryer can be controlled by a scrubber that will reduce the emissions by 90 percent, or 82.8 tons per year as shown in Table 6-15. The second operation is the presently uncontrolled bisque kiln, which emits 60 tons of hydrocarbons per year. The kiln can be controlled with an afterburner that will reduce emissions by 95 percent, or 57 tons per year.

Table 6-15. PARTICULATE EMISSIONS FROM CHAMPION SPARK PLUG COMPANY

Operation	Present controls	Particulate emissions, tons/yr	Good control efficiency, %	Possible reduction, tons/yr
Spray dryer	None	92	90	82.8
Bisque kiln	None	60	95	57
Total		152		139.8

6.5.8.2.2 Methylamine and dimethylformamide production. The Chinook Chemical Company produces methylamines and dimethylformamides. The methylamines are quite odorous and have a high vapour pressure at normal ambient temperatures. The leakage of a small amount of this gas can be detected by its odor at great distances from the plant.

Pump glands, sampling points, and other sources of emissions are now hooded so that emissions are collected for incineration in the plant boiler. Detailed daily inspections for leakages from equipment are being carried out.

6.5.8.2.3 Carbon black production. The Cabot Carbon Company produces carbon black by thermally cracking an aromatic tar fraction, thereby causing the emission of approximately 90,000 tons of carbon monoxide per annum. This emission could be reduced considerably if the gas were burned in a carbon monoxide boiler.

6.5.9 Grey-Iron Foundries

The grey-iron cupola is used to melt scrap iron, steel, and pig iron to make grey-iron castings. A cupola is a vertical, refractory-lined furnace equipped with air ports (known as tuyeres) at the bottom. Air is supplied from a forced-draft blower. Alternate charges of metal, coke, and limestone are placed on top of the burning coke bed to fill the cupola. The heat generated melts the metal, which is drawn off through a tap hole.

The particles emitted from cupolas range in size from coarse to submicron. A simple water-spray system will collect the coarse material. A medium-efficiency scrubber will give a moderate degree of control, but a high degree of control can be achieved only with high-energy scrubbers, electrostatic precipitators, or baghouses.

Los Angeles County was the first area to require a high degree of control of cupolas. A baghouse proved to be the choice of most of the foundry operators. Although difficulties with it were encountered by some operators, the baghouse has been proven to be a feasible control device for cupolas of all sizes. Electrostatic precipitators were installed on a few cupolas, but with less success. Fluctuations in effluent volumes, temperatures, humidities, and particle characteristics caused collection efficiencies to vary. No new electrostatic precipitators have been installed in recent years.

Recently a number of large-production cupolas have been controlled with venturi scrubbers having pressure drop of about 60 inches. Reports indicate that these installations are proving successful.

Emissions from grey-iron foundries and possible reductions are given in Table 6-16. It was assumed that a collector of 99 percent efficiency was feasible for any foundry melting more than 15,000 tons of iron per year. For foundries melting between 3,000 and 15,000 tons per year it was assumed that a scrubber of 90 percent efficiency was feasible. For foundries melting less than 3,000 tons per year, it was assumed that a scrubber of 60 percent efficiency was feasible. Ford Motor Company is in the process of upgrading the scrubbers at the Dearborn Foundry. Kelsey-Hayes Company plans to install new afterburners and a new gas cooling and controlling system for their baghouse collectors. Chrysler Corporation plans to overhaul and improve the scrubber at their Huber Foundry. Huron Valley Steel plans to install a venturi scrubber.

6.6 SOLVENT EVAPORATION

Hydrocarbon emissions in the study area totalled 555,707 tons per year in 1967. Solvent emissions from surface coating operations, degreasing, and dry cleaning account for 12.9 percent of this total. Surface coating and degreasing produce 54,186 tons of hydrocarbon emissions per year. Point sources (100 tons per year or more from a source) of surface coating operations emit more than 29,950 tons of solvent per year. Dry-cleaning establishments emit 8,232 tons per year.

Table 6-16. EMISSIONS FROM GREY-IRON FOUNDRIES

Company	Iron melted, tons/yr	Present controls		Emissions, tons/yr	Possible reduction, tons/yr
		Type	Efficiency, %		
Ford, Dearborn Foundry	630,000	Scrubber	0 to 93	2,643[a]	2,590
Ford, Specialty Foundry	158,000	Scrubber	0 to 98	498[a]	484
G. M. Pontiac Division	331,487	Scrubber	70	855	826
Chrysler, Huber Foundry	121,000	Scrubber	97	32	22
Kelsey-Hayes Company	106,000	Baghouse	0 to 99[a] (70 avg.)	278	269
Huron Valley Steel	70,000	None		609	603
The Budd Company	115,000	Scrubber	90	92	80
Apex Foundry	5,500	None		44	40
Littite Foundries	4,413	None		38	34
Industrial Castings	1,170	None		10	6
Atlas Foundry	1,266	None		11	6
Holmes Foundry	48,000	Wet cap	65	141	137
Ford, Windsor	160,000	Scrubber and baghouse	0 to 99[a]	420[a]	406
Chrysler, Windsor[b]	80,000	Baghouse	0 to 99[a]	363[a]	356
Martin Foundries	6,500	Wet cap	70	16	10
Total				10,279	9,736

[a] Reflects collector down-time; emissions not drawn into the exhaust system.

[b] Shut down since survey.

Solvents used in these operations are either petroleum solvents or halogenated hydrocarbons. Petroleum solvents are varying mixtures of olefins, paraffins, and aromatics, with composition depending on the specific use of the solvent. Halogenated hydrocarbon solvents are usually chlorinated. Some solvents are toxic and may produce problems in the immediate area; others may cause odor problems in limited areas. Tests have shown that certain hydrocarbons used in these solvents are instrumental in the formation of photochemical smog. These tests have led to the regulation of solvent composition, so that some solvents are exempted and the emissions from others are limited. For example, Los Angeles' Rule 66 classifies as photochemically reactive those solvents that contain: (1) 5 percent or more of organic compounds containing an olefinic type of unsaturation; or (2) 8 percent or more of C_8 or higher aromatics, except ethylbenzene; or (3) 20 percent ethylbenzene, toluene, branched ketones, or trichloroethylene; or (4) any combination of the above classes of compounds that totals 20 percent. Exempt (nonphotochemically reactive) solvents include saturated paraffins, including halogenated derivatives, and perchlorethylene. Compliance with a rule of this type requires the reformulation of most of the solvents normally used.

Surface coating operations that are point sources, such as painting and wire enameling, are listed in Table 6-17. Under Rule 66, all bake ovens must be controlled even if the solvent used is exempt. Afterburners are usually used to control bake-oven emissions. Because the oven emissions are at an elevated temperature, less heat from the afterburner is needed for complete combustion. Normal painting and drying operations require control for non-exempt solvents. These emissions are at a lower temperature and are more feasibly controlled by solvent reformulation. Activated carbon units could be used to control surface coating emissions. These units, however, are usually not considered economically feasible.

Table 6-17. SOLVENT EMISSIONS FROM SURFACE COATING OPERATIONS

Company	Emissions, tons/yr
Chrysler Corporation (10 plants)	13,912
General Motors, Fisher Body - Fleetwood	3,000
General Motors, Pontiac Division	2,467
Wolverine Aluminum Company	1,015
Detroit Gravure Corporation	844
Whitehead and Kales	788
Acme Quality Paint	616
St. Clair Rubber Company	599
Dana Corporation	500
Cadillac Motor Car Company	458
R. C. Mahon Company	437
Firestone Steel Products Company	400
American Can Company	391
Evans Products Company	250
Export Processing Company	205
Ford Motor Company	185
Unistrut Corporation	155
Lear Siegler, Automotive Division	147
Bathey Manufacturing Company	105
Chrysler, Windsor	2,760
Plasticast	149
Motor Wheel	115
International Harvester	458
Total	29,956

Point source emissions from degreasing operations are listed in Table 6-18. Degreasing is usually done in a tank containing trichloroethylene vapor. A water jacket around the top of the tank condenses the vapor at that level and the condensate returns into the tank. Some of the vapor escapes to the atmosphere, however, when parts that have been degreased are removed.

Table 6-18. SOLVENT EMISSIONS FROM DEGREASING OPERATIONS

Company	Emissions, tons/yr
Young Spring and Wire Company	400
Brass Craft Manufacturing Company	288
Hoskins Manufacturing Company	135
Wolverine Tube Division, Calumet and Hecla	131
Huck Manufacturing Company	118
Prestolite Wire and Cable	118
Total	1,190

Dry-cleaning establishments use either petroleum solvents or perchlorethylene, usually the latter. The petroleum solvents are usually photochemically reactive. Control of these emissions could be effected by using perchlorethylene or a nonphotochemically reactive petroleum solvent.

Solvent emissions from miscellaneous operations in Canada that are point sources are given in Table 6-19.

Table 6-19. SOLVENT EMISSIONS FROM MISCELLANEOUS OPERATIONS IN CANADA

Company	Operation	Emissions, tons/yr
Calvert	Transer and storage of alcohol	128
Ethyl	Process	486
E. I. DuPont	Process	2,800
Fiberglas	Process	85
Dow Chemical	Process	11,466
Polymer	Process	14,075
Cabot Carbon	Process	3,540
Total		32,580

6.7 AUTOMOBILES

All new motor vehicles sold in Michigan and Ontario are required by law to meet certain emission standards for carbon monoxide and hydrocarbons. Indications are that additional reductions will be required in these emissions as well as oxides of nitrogen emissions.

Furthermore, it appears that controls for pre-1968 and -1969 model vehicles will become a reality and that individual States and Provinces will require their installation.

6.8 REFERENCES FOR SECTION 6

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7. TOTAL COST OF REMEDIAL MEASURES

To ascertain the costs of implementing remedial measures for the study area, it was necessary to utilize a mathematical model and approach the problem on an area basis.

Consideration of the measurements presented in Section 2 indicates that in the Detroit – Windsor and Port Huron – Sarnia areas of the United States and Canada, as in most urban industrialized areas, the principal pollutants degrading air quality are particles and sulfur dioxide. Reduction of the ambient concentrations of these pollutants can be effected only through the control of emissions at the sources.

7.1 PARTICLE CONTROL

Various strategies for the control of particles were investigated through a mathematical dispersion model. These strategies were based on control regulations in existence in several political jurisdictions in the Michigan portion of the area. Ontario regulations are based on concentrations at the point of impingement of the stack plume rather than on mass emission rates.

Of four strategies tested with the dispersion model, one set of regulations now in force produced the greatest improvement in air quality when applied to point sources. The features of this regulation (referred to below as Regulation A), in terms of allowable rate of discharge for heat input and process weight, are illustrated in Figure 7-1.

7.1.1 Detroit – Windsor Area

The mathematical model was applied to emissions in the Detroit–Windsor area with all point source emissions reduced to comply with Regulation A. Even with this degree of control, 28 of the 34 receptor sites considered by the model showed average annual concentrations of 65 $\mu g/m^3$ or more. Twenty-three sites showed concentrations of 75 $\mu g/m^3$ or more; 13 had concentrations of 90 $\mu g/m^3$ or more; and 7 had concentrations of 100 $\mu g/m^3$. These concentrations indicate that greater control is required than that afforded by Regulation A.

Table 7-1 shows the relative contributions of these sources to the pollution at each receptor site. The large contribution from area sources to the pollution at each receptor site makes obvious the need for control of the many small sources that individually do not emit sufficient particles to be considered point sources.

Based on projections made by the U.S. Bureau of Mines, Sartorius and Company, and Texas Eastern Transmission Corporation, a 45-percent reduction in coal usage for residential, commercial, and governmental heating can be anticipated with a corresponding increase in the use of distillate oil and natural gas. This reduction in emissions, coupled with a ban on open burning, would produce a maximum reduction in area-source emissions of 50 percent.

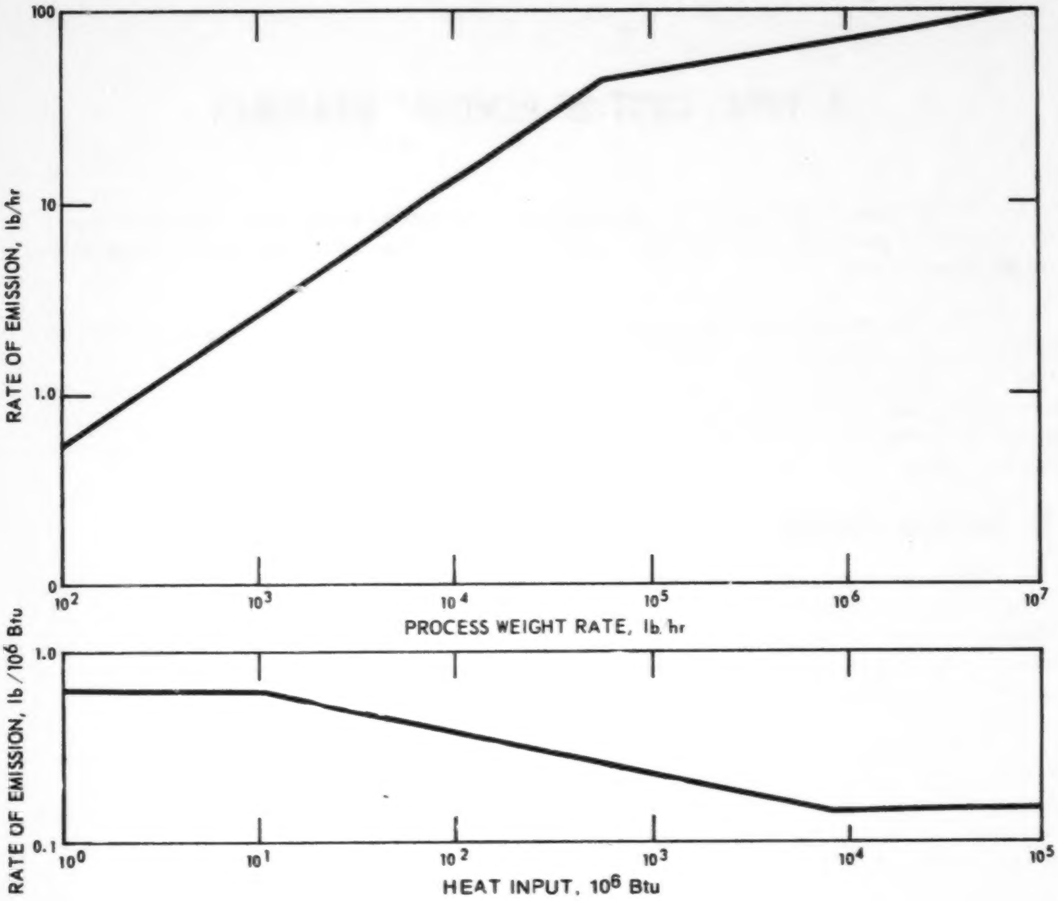

Figure 7-1. Particulate emission regulations (Regulation A).

Assuming a 50-percent reduction in area-source emissions, and applying Regulation A to all point sources, the mathematical model shows (Table 7-3) that 22 of the 34 receptor sites have annual average concentrations of 60 $\mu g/m^3$ or greater. Of these, 19 have concentrations greater than 65 $\mu g/m^3$, 10 greater than 75 $\mu g/m^3$ and 2 greater than 90 $\mu g/m^3$; none has a concentration as large as 95 $\mu g/m^3$.

7.1.2 Port Huron — Sarnia Area

Application of Regulation A in the Port Huron — Sarnia area again indicates that control of point sources alone will not provide adequate air quality improvement. Of the 20 receptor sites considered by the model in this area, 15 have particulate concentrations equal to or greater than 60 $\mu g/m^3$. Of these, 10 have concentrations equal to or greater than 65 $\mu g/m^3$ and 3 have concentrations equal to or greater than 75; none exceeded 80 $\mu g/m^3$.

The importance of the area sources to uncontrolled particulate pollution is indicated by the relative contributions at each receptor site shown in Table 7-2.

Table 7-1. RELATIVE CONTRIBUTIONS OF SOURCES TO GROUND-LEVEL CONCENTRATIONS OF PARTICLES AND SULFUR OXIDES[a] IN DETROIT - WINDSOR AREA

Receptor site	Contribution of particles,[b] %			Contribution of sulfur oxides, %		
	Fuel combustion	Industrial processes	Area sources	Fuel combustion	Industrial processes	Area sources
201	17	48	35	44	13	43
202	14	55	31	38	22	40
203	19	51	30	53	17	30
204	18	17	65	-	-	-
205	19	22	59	38	4	58
206	17	33	50	47	7	46
207	18	29	53	49	6	45
209	19	4	77	31	1	68
210	25	28	47	47	1	52
211	27	22	51	41	3	56
212	25	36	39	49	9	42
213	23	20	57	39	1	60
214	29	20	51	43	3	54
215	22	25	53	40	4	56
216	17	18	65	38	3	59
217	15	14	71	32	3	65
218	18	16	66	41	3	56
219	19	6	75	34	1	65
220	11	65	24	42	20	38
400	20	11	69	32	3	65
401	18	4	78	31	1	68
402	15	6	79	24	1	75
403	18	6	76	29	1	70
404	18	5	67	34	4	62
406	17	49	34	44	20	36
407	14	48	38	34	27	39
409	34	25	41	43	4	53
411	21	45	34	45	3	52
412	18	25	57	43	1	56
413	29	27	44	39	8	53
414	13	7	80	22	2	76
415	11	31	58	33	13	54
416	15	17	68	28	4	68
417	11	23	66	39	2	59
418	11	12	77	36	1	63
419	12	4	84	17	1	82
422	7	12	81	16	3	81
423	6	7	87	16	2	82
425	9	12	79	18	3	79
426	3	3	94	-	-	-
427	3	2	95	-	-	-
Average	17	26	56	36	8	56

[a] Percentages calculated from model estimates without compensation for background concentrations.

[b] The remaining 1 percent is contributed by refuse disposal sources.

Table 7-2. RELATIVE CONTRIBUTIONS OF SOURCES TO GROUND-LEVEL CONCENTRATIONS OF PARTICLES AND SULFUR OXIDES[a] IN PORT HURON - SARNIA AREA

Receptor site	Contribution of particles, %			Contribution of sulfur oxides, %			
	Fuel combustion	Industrial processes	Area sources	Fuel combustion	Industrial processes	Area sources	Refuse disposal
151	46	15	39	54	23	21	2
153	17	3	80	36	4	58	2
154	34	10	56	48	9	41	2
155	42	12	46	61	17	18	4
156	20	3	77	60	2	37	1
157	24	2	74	72	1	26	1
158	46	11	43	56	17	23	4
159	14	5	81	56	0	44	0
160	43	6	51	56	12	29	3
161	34	7	59	64	5	25	6
162	11	2	87	57	0	43	0
163	10	1	89	52	0	48	0
164	8	1	91	45	0	55	0
165	4	1	95	29	0	71	0
166	22	2	76	42	3	53	2
167	9	1	90	46	0	54	0
301	41	11	48	53	10	35	2
303	44	5	51	67	3	27	3
305	21	2	77	66	1	32	1
307	12	1	87	55	0	45	0
308	32	10	58	46	8	44	2
310	47	10	43	56	13	28	3
311	21	2	77	56	2	40	2
312	20	3	77	68	0	32	0
313	8	1	91	35	1	64	0
314	28	4	68	45	4	49	2
315	10	2	88	30	2	67	1
316	9	1	90	37	0	63	0
317	5	1	94	22	1	76	1
318	5	1	94	18	1	80	1
319	4	1	95	21	0	79	0
Average	27	6	67	53	7	38	2

[a] Percentages calculated from model estimates without background concentrations.

A 50-percent reduction of area-source emissions effected through fuel changes and banning of open burning, in addition to the enforcement of Regulation A with respect to point sources, would produce an acceptable air quality for the region. Model calculations show (Table 7-3) that only 5 of the 20 receptor sites have concentrations equal to or greater than 60 $\mu g/m^3$. Only one site exceeded 65 $\mu g/m^3$ and none exceeded 70 $\mu g/m^3$.

7.2 SULFUR DIOXIDE CONTROL

None of the local control regulations in the Michigan portion of the region specify restrictions on sulfur dioxide emissions, and the Ontario regulations limit emissions on the basis of concentrations in the stack effluent plume at the point of impingement. Accordingly, three arbitrary control strategies restricting sulfur dioxide emissions were tested with the mathematical model. Two of these

Table 7-3. GROUND-LEVEL CONCENTRATIONS OF PARTICLES AND SULFUR OXIDES IN THE DETROIT - WINDSOR AREA[a]

Receptor site	Particulate concentration, μg/m^3		SO_x concentration, ppm	
	Observed, 1968	Projected, current	Observed, 1968	Projected, current
201	110.0	65.8	0.024	0.0078
202	133.0	75.5	0.037	0.0119
203	183.0	93.8	0.053	0.0193
204	137.0	86.0	-	-
205	140.0	91.8	0.026	0.0098
206	129.0	76.8	0.022	0.0074
207	101.0	66.5	0.024	0.0080
209	91.0	64.1	0.024	0.0097
210	-	-	0.026	0.0092
211	76.0	54.1	0.018	0.0065
212	79.0	54.7	0.015	0.0050
213	-	-	0.015	0.0058
214	-	-	0.024	0.0087
215	97.0	63.1	0.018	0.0066
216	-	-	0.018	0.0069
217	77.0	56.5	0.013	0.0047
218	-	-	0.020	0.0074
219	-	-	0.015	0.0060
220	120.0	68.2	0.024	0.0075
400	107.0	73.5	0.035	0.0096
401	71.0	55.2	0.022	0.0090
402	111.0	77.6	0.027	0.0115
403	96.0	66.7	0.031	0.0127
404	136.0	85.2	0.037	0.0142
406	152.0	86.2	0.046	0.0141
407	136.0	80.4	0.042	0.0132
409	103.0	63.3	0.024	0.0086
411	85.0	53.6	0.027	0.0096
412	69.0	52.6	0.022	0.0080
413	-	-	0.020	0.0071
414	127.0	82.5	0.027	0.0129
415	115.0	72.4	0.027	0.0098
416	85.0	59.8	0.020	0.0079
417	73.0	54.3	0.015	0.0058
418	78.0	58.1	0.013	0.0051
419	92.0	66.0	0.018	0.0081
422	105.0	71.6	0.022	0.0097
423	71.0	55.3	0.013	0.0058
425	68.0	46.4	0.011	0.0047
426	93.0	66.4	-	-
427	46.0	42.9	-	-

[a] Regulations for particle control and 80-percent reduction of SO_2 applied to all point sources; 50-percent reduction applied to all area source emissions.

strategies were more effective than the third and gave similar results. One of these called for an across-the-board reduction of 80 percent of all sulfur dioxide emissions, whereas the other required an 80-percent reduction in emissions from combustion units burning more than 40,000 tons of coal per year and a limitation of emissions from sulfuric acid plants to 2,000 ppm sulfur dioxide. The first of these two reduction plans produced slightly more improvement in the computed air quality and has been used in illustrating control strategies.

7.2.1 Detroit – Windsor Area

Model computations show that the emission control strategy selected above will provide a reasonable air quality with respect to sulfur dioxide in the Detroit-Windsor area. Of the 38 receptor sites considered by the model, 32 have concentrations less than 0.020 ppm, 27 less than 0.0175 ppm, 20 less than 0.0150, 14 less than 0.0125, and 4 less than 0.0100 ppm.

Table 7-1 shows the relative importance of area sources of sulfur dioxide to the total concentrations measured at the receptor sites.

A reduction of 50 percent in the area-source emissions of sulfur dioxide produces a substantial reduction in ground-level concentrations according to model computations. When both point and area sources are controlled (Table 7-3), only one of the 38 receptor stations considered by the model had an annual average concentration greater than 0.015 ppm, and only 8 had concentrations greater than 0.010 ppm.

7.2.2 Port Huron – Sarnia Area

Model estimates using a reduction of 80 percent for all point sources in the Port Huron – Sarnia area show that none of the receptor stations had a concentration exceeding 0.017 ppm on an annual average basis. Only one station had a concentration greater than 0.015 ppm; 19 of the 28 stations considered had 0.010 ppm or greater.

Application of a 50-percent reduction to the sulfur dioxide emissions of all area sources, in addition to point source reductions, limits concentrations at all the receptor stations to less than 0.010 ppm on an annual average basis. Twenty-two of the 28 stations had concentrations of 0.007 ppm or less.

Ground-level concentrations based on projected 1975 emissions are given for the Port Huron – Sarnia area in Table 7-4.

7.3 COSTS OF CONTROL

Cost of compliance with Regulation A for the control of particles and for an 80-percent reduction in sulfur dioxide emissions is an important factor that must be weighed against air quality goals.

Changes in area-source emissions postulated to improve the air quality have been assumed to take place as a result of progressive alteration of fuel usage and equipment updating without specific modifications to assure compliance with emission regulations. Accordingly, cost estimates have been based on equipment and operating charges that must be met by point-source operators in order to restrict emissions of particles and sulfur dioxide.

Table 7-4. GROUND-LEVEL CONCENTRATIONS OF PARTICLES AND SULFUR OXIDES IN THE PORT HURON - SARNIA AREA[a]

Receptor site	Particulate concentration, $\mu g/m^3$		SO_x concentration, ppm	
	Observed, 1968	Projected, current	Observed, 1968	Projected, current
151	103	64	0.035	0.009
153	68	53	0.013	0.005
154	119	-	0.022	0.007
155	101	66	0.029	0.007
156	64	52	0.024	0.008
157	-	-	0.022	0.006
158	92	60	0.022	0.006
159	69	56	0.042	-
160	70	53	0.026	0.007
161	85	62	0.024	0.007
162	-	-	0.018	0.006
163	64	52	0.009	0.003
164	-	-	0.009	0.003
165	-	-	0.011	0.005
166	-	-	0.013	0.005
167	-	-	0.013	0.005
301	91	59	-	-
303	76	57	-	0.008
305	71	57	-	-
307	64	53	0.015	0.005
308	-	-	0.022	0.007
310	95	61	0.031	0.009
311	-	-	0.020	0.006
312	-	-	0.024	0.007
313	-	-	0.018	0.007
314	65	51	0.020	0.007
315	53	46	0.022	0.009
316	52	46	0.020	0.008
317	66	53	0.013	0.005
318	48	44	0.013	0.006
319	53	46	0.013	0.006

[a] Regulations for particle control and 80-percent reduction of SO_2 applied to all point sources; 50-percent reduction of area source emissions.

At the time of this study, fuel substitution, from coal to low-sulfur oil or from coal to natural gas, was the most feasible method for achieving the required reduction of sulfur dioxide emissions from industrial boilers. No added collectors were necessary for controlling particles (see Section 6 for control technology). When the emission survey was made, in 1967, all power plants in the area were burning coal, and only one could achieve the required reduction in sulfur dioxide emissions by switching to coal of the lowest available sulfur content (0.7 percent). This particular plant was meeting the particulate emission restrictions with its current practices and needed no additional control equipment. Both fuel substitution and flue-gas scrubbing were investigated as alternative methods for reducing sulfur dioxide emissions at the remaining power plants. For seven of these plants, however, data were not available for accurate estimates of flue-gas scrubbing requirements and costs.

The majority of the industrial-process point sources have equipment for at least partially controlling particulate emissions. The costs of add-on equipment necessary to attain the desired control were estimated for these sources. Since this additional equipment must remove the fine particles not controlled by existing devices, only wet scrubbers, electrostatic precipitators, or fabric filters were considered.

For sources with no existing gas-cleaning equipment, literature surveys determined the feasible control alternatives. Equipment capacities were determined from gas-flow rates or process weights, according to which was available.

Reduction of sulfur dioxide emissions from industrial processes frequently requires process changes and each plant must be considered individually. Estimates of annual costs for control have been based largely on data from the literature on modification of similar plants.

The emission sources for which control costs were estimated are industrial boilers, power plants, and industrial processes.

The annual costs for the control of particles and sulfur dioxide for these sources are given in Table 7-5.

Table 7-5. ANNUAL COSTS OF CONTROL OF PARTICLES AND SULFUR DIOXIDE

Source	Estimated annual least cost, $		Substitution and fuel switching	Flue-gas scrubbing[a]
	Low	High		
Industrial boilers	45,585,503	45,585,503	45,585,503	
Power plants	15,479,480	15,479,480	96,115,775	13,198,839
Industrial processes	4,007,597	5,139,573		
Total	65,072,580	66,204,556		

[a] Flue-gas scrubbing cost could not be estimated for seven plants because of lack of necessary information.

It should be noted that the flue-gas scrubbing costs are based upon results of experimental work performed by the Tennessee Valley Authority and should be used with that understanding.

Annual control cost figures do not include estimates for the sources presented in Table 7-6.

In general, the method used to estimate control costs involved three steps:

1. Categorization of sources.
2. Identification of particulate and sulfur dioxide control alternatives capable of achieving the desired reductions for each category.
3. Estimation of the annual cost associated with each alternative.

Table 7-6. SOURCES EXCLUDED FROM COST ESTIMATES

Source code	Source	Explanation
21	Stucco process	Improved maintenance practices to meet reduction requirements
27	Rotary kiln	Concentration too low to control
29	Rotary kiln	No need to control cement kiln for SO_2
30	Combustion units	Emissions <2.3 lb $SO_2/10^6$ Btu
34	Coal stoker	Emissions <2.3 lb $SO_2/10^6$ Btu
37	Annealing and casting	Concentration too low
46	Iron cupolas	SO_2 from gray-iron foundries not usually controlled
61	Kilns	No need to control cement kiln for SO_2
107	Foundry cleaning	Improved maintenance practice to meet reduction requirements
127	Gas and oil combustion	Emissions <2.3 lb $SO_x/10^6$ Btu
128	Carbon monoxide boiler combustion	Emissions <2.3 lb $SO_x/10^6$ Btu
129	Various heaters, combustion	Emissions <2.3 lb $SO_x/10^6$ Btu
130	Gas reboilers, combustion	Emissions <2.3 lb $SO_x/10^6$ Btu
131	Cokers and reboilers, combustion	Emissions <2.3 lb $SO_x/10^6$ Btu
136	Incinerator	Unable to control SO_2
137	Incinerator	Unable to control SO_2
138	Incinerator	Unable to control SO_2
139	Incinerator	Unable to control SO_2
144	Incinerator	Unable to control SO_2
166	Sintering plant	Unable to control SO_2
168	Blast furnace	Improved maintenance practices to meet reduction requirements
214	Coking process	No additional control available
238	Casting cleaning	Improved maintenance practices to meet reduction requirements
241	Iron-melting cupola	Insufficient information
243	Phenolic-curing oven	Insufficient information
244	Cupola process	Has been replaced by electric industrial furnace
266	Incinerator	Unable to control SO_2
267	Incinerator	Unable to control SO_2
268	Incinerator	Unable to control SO_2
269	Incinerator	Unable to control SO_2
404	Stone crusher	Insufficient information
435	Gas boilers	Emissions <2.3 lb $SO_x/10^6$ Btu
454	DEA regeneration	Insufficient information

7.3.1 Industrial Boilers

The following procedures were used in the Detroit Study to estimate the annual cost of reducing present sulfur dioxide and particulate emissions that result from combustion of coal or oil in industrial boilers. Sulfur dioxide and particulate control alternatives considered were fuel substitution and fuel switching. Mechanical collectors were not added to coal-burning boilers because the strict sulfur dioxide reduction (80 percent) would force a switch from coal to low-sulfur oil or coal to natural gas.

Since an 80-percent reduction in annual sulfur dioxide emissions for all point sources was desired, the procedures first determined the percentage sulfur in fuel required to achieve that reduction. The annual cost of sulfur dioxide control was estimated on the basis of (1) the difference in cost ($\$/10^6$ Btu) of the present fuel and the proposed fuel (Table 7-7) and, (2) the total energy consumed annually in Btu's. Costs for boiler modifications were omitted inasmuch as these costs represent only one or two percent of the total annual cost.[4] The assumption was made that switching from coal to natural gas or from oil to natural gas will be allowed only when the sulfur dioxide regulation cannot be met by switching to low-sulfur oil. The assumption was made because of uncertainty regarding fuel availability. For example, should a large industrial plant or electric utility wish to change to gas for pollution control purposes, negotiation between the gas distributor and the potential gas consumer would be the only way to determine availability to that customer. Also, supplying a large consumer would probably call for expansion of existing gas facilities, at the distribution and/or the transmission level.

Table 7-7. FUEL COSTS FOR DETROIT STUDY

Type	Sulfur content, %	Fuel cost, ¢/10^6 Btu	
		Power plants	All other users
Bituminous coal	>3.00	28[b]	32[1]
	2.00	30[b]	33
	1.00	33[b]	35
	0.70	36[a]	40
Residual oil			
No. 6	>1.00	48[b]	56[1]
No. 5	0.75	52[b]	58[1]
Distillate oil			
No. 2	0.25	69[b]	77[1]
No. 1	0.07	77[b]	85[1]
Natural gas	0.00	50[b]	55[1]

[a] Based upon information obtained from the Fuel Policy Section, Office of Program Development, National Air Pollution Control Administration.

[b] No prices for fuel oil or natural gas for power plants were available. It was assumed, therefore, that the cost of fuel oil and natural gas to power plants would be approximately 90 percent of the cost of fuel oil and natural gas to industrial users.

It was assumed that industrial boilers burning low-sulfur oil or natural gas will always meet the desired particulate emission reduction.

7.3.1.1 Fuel Substitution - Calculations for estimating the costs of substituting low-sulfur oil for high-sulfur oil are presented below. Costs are shown in Table 7-8.

Table 7-8. COST OF FUEL SUBSTITUTION

Sulfur content of oil, %	Cost, ¢/10^6 Btu
2.50	56
2.00	56
1.50	56
1.00	56
0.25	77
0.07	85

1. Multiply present percentage sulfur in oil by 0.2 to give the allowable percentage sulfur content of the oil.
2. Compute the difference in cost between the present oil and the proposed oil (Δ¢/10^6 Btu).
3. Compute the total Btu's of oil consumed:

$$\text{Total annual cost} = \frac{\text{Total Btu}}{10^6} \quad (\Delta¢/10^6 \text{ Btu})$$

7.3.1.2 Fuel Switching - Calculations for estimating the costs of substituting fuels are presented below. Costs are shown in Tables 7-9 through 7-13.

Table 7-9. COST OF COAL

Sulfur content of coal, %	Cost, ¢/10^6 Btu
>3	32
2	33
1	35
0.7	40
<0.7[a]	-

[a] Coal of this sulfur content is not available.

7.3.1.2.1 Coal to low-sulfur oil.

1. Multiply the present annual emission of SO_x (in pounds) by 0.2 to give the permissible SO_x emissions.
2. Compute the total Btu's of coal consumed per year,
   Total Btu = (lb) (Btu/lb)
3. Compute the cost of coal presently being used.
   Present cost = Total Btu (¢/10^6 Btu)
4. Correct for boiler efficiency (coal to oil).
   $$\text{Corrected total Btu} = \left(\frac{87}{86}\right)\text{total Btu}$$
5. Determine the correct sulfur fuel content to use.
   $$\text{Sulfur content} = \frac{\text{lb permissible } SO_x \text{ emissions}}{\text{Corrected total Btu}/10^6} = \text{lb}/10^6 \text{ Btu}$$

Table 7-10. COST OF OIL

Sulfur content of oil, %	SO_x, lb/10^6 Btu[a]	Cost, ¢/10^6 Btu
2.50	2.68	56
2.00	2.14	56
1.50	1.67	56
1.00	1.07	56
0.25	0.26	77
0.07	0.07	86

[a] Based on 148,000 Btu per gallon of oil.

6. Compute the cost of the proposed fuel oil.
   Projected cost = Corrected total Btu (¢/10^6 Btu)
7. Compute total annual cost.
   T.A.C. = Future cost (from Step 6) - Present cost (Step 3)

7.3.1.2.2 Coal to natural gas. Use this alternative only if switching from coal to low-sulfur oil does not satisfy sulfur emission regulations.

1. Compute the total Btu's of coal consumed.
   Total Btu = (lb) (Btu/lb)
2. Compute the cost of coal presently being used.
   Present cost = Total Btu (¢/10^6 Btu)
3. Correct for boiler efficiency.
   $$\text{Corrected total Btu} = \text{Total Btu}\left(\frac{87}{82}\right)$$
4. Compute the cost of the proposed natural gas (firm).
   Future cost = Corrected total Btu (¢/10^6 Btu)
5. Compute total annual costs.
   T.A.C. = Future cost (Step 4) - present cost (Step 2)

Table 7-11. COST OF COAL

Sulfur content of coal, %	Cost, ¢/10^6 Btu
>3	32
2	33
1	35
0.7	40
<0.7[a]	-

[a] Coal of this sulfur content is not available.

7.3.1.2.3 High-sulfur oil to natural gas. Use this alternative only if switching from high-sulfur oil to low-sulfur oil does not satisfy sulfur emission regulations.

1. Compute the total Btu's of oil consumed.
   Total Btu = (lb) (Btu/lb)
2. Compute the cost of the oil presently being used.
   Present cost = total Btu (¢/10^6 Btu)

Table 7-12. COST OF OIL

Sulfur content of oil, %	Cost, ¢/10^6 Btu
2.50	56
2.00	56
1.50	56
1.00	56
0.25	77
0.07	85

3. Correct for boiler efficiency.
   Corrected total Btu = total Btu $\left(\frac{86}{82}\right)$
4. Compute the cost of the proposed natural gas.
   Future cost = Corrected total Btu (55¢/10^6 Btu)
5. Compute total annual costs.
   T.A.C. = Future cost (from Step 4) - present cost (from Step 2)

7.3.2 Power Plants

Control costs for power plants are based upon economic evaluation of three control alternatives: (1) fuel substitution, (2) fuel switching, and (3) flue-gas scrubbing.

7.3.2.1 Fuel Substitution: Coal to Low-Sulfur Fuel - All power plants are presently burning coal. Only one of these power plants could achieve an 80-percent reduction in present sulfur dioxide emissions by switching to low-sulfur coal. Other power plants would require coal with a sulfur content of less than 0.7 percent. Because the cost of low-sulfur-content coal (less than 0.7 percent) is not known, and because its availability is uncertain, sulfur dioxide reduction alternatives other than fuel substitution were used for economic evaluation of the remaining power plants. The power plant that could use fuel substitution is meeting the particulate regulation; therefore, control costs for additional particulate control equipment were not estimated.

1. Multiply the percentage sulfur in coal by 0.2 to give the allowable percentage sulfur in coal. If the allowable percentage in coal is <0.7, use other sulfur dioxide reduction alternatives.
2. Compute the difference in cost between the present and proposed fuels ($\Delta¢/10^6$ Btu).

Table 7-13. COST OF COAL

Sulfur content of coal, %	Cost, $¢/10^6$ Btu
>3	28
2	30
1	33
0.7	36

3. Compute the total Btu's of coal consumed.
   Total Btu = (pounds of coal currently consumed) (Btu/lb)
4. Compute the total annual costs.

$$\text{T.A.C.} = \left(\frac{\text{total Btu}}{10^6}\right) \quad (\Delta¢/10^6\ \text{Btu})$$

7.3.2.2 Fuel Switching - Procedures are given only for calculating costs of switching from coal to low-sulfur oil and coal to natural gas. The procedures are similar to the ones presented in Section 7.3.1 for control of emissions from industrial boilers. Costs are shown in Tables 7-14, 7-15, and 7-16.

7.3.2.2.1 Coal to low-sulfur oil.

1. Multiply the present annual emission of SO_x (in pounds) by 0.2 to give the permissible pounds of SO_x emissions.
2. Compute the total Btu's of coal consumed per year.
   Total Btu = (lb) (Btu/lb)
3. Compute the cost of the coal presently being used.
   Present cost = total Btu ($¢/10^6$ Btu)
4. Correct for boiler efficiency (coal to oil).

$$\text{Corrected total Btu} = \text{total Btu}\left(\frac{87}{86}\right)$$

Table 7-14. COST OF COAL

Sulfur content of coal, %	Cost, ¢/10^6 Btu
>3	28
2	30
1	33
0.7	36

5. Determine the correct percentage sulfur content of fuel oil.

Table 7-15. COST OF OIL

Sulfur content of oil, %	SO_x, lb/10^6 Btu[a]	Cost, ¢/10^6 Btu
2.50	2.68	48
2.00	2.14	48
1.50	1.67	48
1.00	1.07	48
0.25	0.26	69
0.07	0.07	77

[a] Based on 148,000 Btu per gallon of oil.

$$\text{S.O.} = \frac{\text{Permissible lb } SO_x \text{ emissions}}{\text{Corrected total Btu}/10^6}$$

6. Compute the cost of the proposed fuel oil.
   Future cost = Corrected total Btu (¢/10^6 Btu)
7. Compute total annual cost of control.

   T.A.C. = Future cost (from Step 6) - present cost (from Step 3)

7.3.2.2.2 Coal to natural gas. Use this alternative only if switching from coal to low-sulfur oil does not satisfy sulfur emission regulations.

1. Compute the total Btu's of coal consumed.
   Total Btu = (lb) (Btu/lb)
2. Compute the cost of the coal presently being used.
   Present cost = total Btu (¢/10^6 Btu)
3. Correct for boiler efficiency.

   $$\text{Corrected total Btu} = \text{total Btu}\left(\frac{87}{82}\right)$$
4. Compute the cost of the proposed natural gas (firm).
   Future cost = corrected total Btu (50¢/10^6 Btu)
5. Compute total annual costs.
   T.A.C. = Future cost (from Step 4) - present cost (from Step 2)

Table 7-16. COST OF COAL

Sulfur content of coal, %	Cost, ¢/10^6 Btu
>3	28
2	30
1	33
0.7	36

7.3.2.3 Flue-Gas Scrubbing - Flue-gas scrubbing control cost calculations are limited to evaluating the use of limestone (or dolomite) in a wet-scrubbing process. The reasons for considering this process as opposed to others are: (1) the dry limestone-injection process has a collection efficiency of only 40 to 60 percent and the reduction to be achieved by the proposed regulation is 80 percent; (2) other processes, such as Reinluft, alkalized alumina, and catalytic oxidation are under study, with no definitive data on the economics involved; (3) a design and cost study recently completed by the Tennessee Valley Authority[5] for NAPCA has applied two variations of the limestone wet-scrubbing process with sulfur dioxide collection efficiencies of greater than 80 percent.

The two processes used by TVA are: (1) injection of pulverized limestone into a boiler with subsequent scrubbing of the flue gases to remove both flyash and sulfur dioxide (Process A), and (2) introduction of lime or pulverized limestone directly into the scrubber recirculating slurry to remove sulfur dioxide and flyash (Process B). The collection efficiencies of the two processes are given in Table 7-17.

Table 7-17. COST OF FLYASH AND SULFUR DIOXIDE REMOVAL BY TVA PROCESSES

Process	Scrubber stages	Flyash removal efficiency, %	SO_2 removal efficiency, %
A	One	98.0	85
A	Two	99.5	95
B	One	98.0	70
B	Two	99.5	85

For a 200-megawatt plant, annual costs for the limestone wet-scrubbing processes were found to vary from $0.64 to $2.10 per ton of coal burned, depending upon factors such as sulfur content of the coal, plant load factor, and raw material cost. A procedure was developed, using cost information given in the TVA report, to estimate the annual control cost for Process A (two-stage scrubbing). Control costs for Process B are omitted since it is more expensive than Process A.

The cost estimating procedures for Process A relate unit size of the power plant, load factor, and sulfur content of the coal to annual operating cost. The following assumptions were used for the annual cost estimates:

1. Load factor of 91 percent.
2. Limestone cost of $2.05 per ton.
3. Operating time of 8,000 hours per year.
4. Sulfur content in coal of 3.5 percent.
5. Ash content in coal of 12.0 percent.
6. Fixed capital charges equal to 14.5 percent of fixed investment.
7. Credits are included for expected boiler corrosion reduction and operating, and investment cost of existing control equipment for eliminating its use.

The annual costs were calculated on the basis of these assumptions with corrections made for the sulfur content of coal and the load factor. The procedure used is given below.

1. Compute the overall investment cost (I.C.) for Process A. The investment cost should be based on the maximum generating capacity of the power plant.[6] The equations are:
   $\text{I.C.} = \$ \times 10^6$, where X = mW rating of power plant
   Process A: $\text{I.C.} = 1.6 + 0.006X$
2. If the sulfur content of the coal is different from 3.5%, correct the overall investment as follows:
   $\Delta 1\% = 10\%$ in overall investment
   $\Delta\text{I.C.} = (\%\ \text{sulfur} - 3.5\%)(0.1)\ \text{I.C.}$
3. Compute total investment cost by adding Steps (1) and (2):
   Total I.C. = I.C. from Step (1) + ΔI.C. from Step (2)
4. Compute the total annual operating cost. This cost includes depreciation, capital charges, taxes, insurance, etc. (Total = 14.50% of I.C. per year).
   Process A: X = mW rating; $\text{O.C.} = \$ \times 10^3$
   (1) If the mW rating is 0 to 540 mW use:
   $\text{O.C.} = 192.3 + 2.959X$
   (2) If the mW rating is > 540 mW use:
   $\text{O.C.} = 736 + 1.981X$
5. Correct operating cost for sulfur content of fuel.
   ($\Delta 1\%$ in sulfur content $= \Delta 13\%$ in O.C.)
   $\Delta\text{O.C.} = (\%\ \text{sulfur} - 3.5\%)(0.13)(\text{O.C.})$
6. Compute total annual operating cost by adding Steps (4) and (5).
   Total O.C. = O.C. from Step 4 + ΔO.C. from Step 5
7. If the actual average load factor is different from 91%, another correction in operating cost must be made:
   a. Calculate the cost per ton of coal at 91% load factor (L.F.) by using the following conversion relation:
      1 mW requires 3,000 tons of coal
      therefore:
      $$\$/\text{ton coal} = \frac{\text{O.C. from Step (6)}}{(3{,}000\ \text{tons/mW})(\text{mW rating of power plant})}$$
   b. Calculate the change in operating cost per ton of coal as follows (for Process A):

(1) If the load factor is 64 to 91%, use (\$/ton coal) = (\$/ton coal at 91%) + (91% - L.F.) (0.00642) (\$/ton coal at 91%)

(2) If load factor is 33 to 64% use:

(\$/ton coal) = 1.2309 (\$/ton coal at 91%)
+ (64% - L.F) (0.0208) (1.2309) (\$/ton coal at 91%)

(3) If load factor is 17 to 33% use:

(\$/ton coal) = (2.0246) (\$/ton at 91%) +
(33% - L.F.) 0.0477 (2.0245)(\$/ton at 91%)

8. Compute total annual control cost.

T.A.C. = present fuel consumption (in tons of coal per year) x
$\frac{\$\underline{\hspace{2cm}}}{\text{ton coal}}$ (from Step 7b)

7.3.3 Industrial Processes

7.3.3.1 Particulate Emissions - At present, industrial sources requiring reductions in particulate emissions are either partially controlled or completely uncontrolled. The costs of controlling respective types of sources are given in the following sections.

7.3.3.1.1 Partially controlled process sources. The majority of sources were partially controlled by equipment designed for a given gas volume. For these sources it is assumed that add-on gas-cleaning equipment will be used to reduce present particulate emissions to the allowable level. If a partially controlled source needed only 10 percent additional control or less to meet the regulation, it was assumed that compliance would be obtained by improving maintenance practices for the existing control equipment, with no major capital expenditure. Equations for annual control costs for three types of particulate gas-cleaning equipment were derived for use in estimating the cost of add-on gas-cleaning equipment. Only wet scrubbers, electrostatic precipitators, or fabric filters are used as add-on gas-cleaning equipment. Only these three types of gas-cleaning equipment are capable of removing fine particles not removed by the existing gas-cleaning equipment. Since detailed information needed to make precise cost estimates was not available, several assumptions were made as required, and low and high annual costs were calculated. The equations given below, which are simplified, express annual cost as a function of gas volume and hours of operation (y = dollars x 10^3; X = acfm x 10^3; ΔH = 8760 - actual hours of operation).

Wet scrubbers

1. Low efficiency, 11 to 83 percent.
   a. Low cost: $y = 0.3224 + 0.1088X - (4.83 \times 10^{-6})\Delta H(X)$
   b. High cost: $y = 0.3224 + 0.2716X - (18.89 \times 10^{-6})\Delta H(X)$
2. Medium efficiency, 84 to 94 percent
   a. Low cost: $y = 0.987 + 0.2164X - (13.03 \times 10^{-6})\Delta H(X)$
   b. High cost: $y = 0.987 + 0.6152X - (51.70 \times 10^{-6})\Delta H(X)$
3. High efficiency, 95 to 99.5 percent.
   a. Low cost: $y = 1.481 + 0.6470X - (55.91 \times 10^{-6})\Delta H(X)$

b. High cost: $y = 1.481 + 2.2202X - (223.21 \times 10^{-6})\Delta H(X)$

Fabric filters

1. Type "A". High-temperature synthetics, woven and felt. Continuous automatic cleaning.
   - a. Low cost: $y = 0.373 + 0.3299X - (3.9 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 0.496 + 0.5044X - (15.6 \times 10^{-6})\Delta H(X)$
2. Type "B". Medium-temperature synthetics, woven and felt. Continuous automatic cleaning.
   - a. Low cost: $y = 0.893 + 0.1995X - (3.9 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 1.192 + 0.3407X - (15.6 \times 10^{-6})\Delta H(X)$
3. Type "C". Woven natural fibers. Intermittently cleaned; single compartment.
   - a. Low cost: $y = 0.683 + 0.138X - (3.9 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 0.900 + 0.2679X - (15.6 \times 10^{-6})\Delta H(X)$

High-voltage electrostatic precipitators

1. Low efficiency, 11 to 87 percent.
   - a. Low cost: $y = 4.714 + 0.0944X - (0.95 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 4.714 + 0.1394X - (3.8 \times 10^{-6})\Delta H(X)$
2. Medium efficiency, 88 to 94 percent.
   - a. Low cost: $y = 9.082 + 0.1497X - (1.3 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 9.082 + 0.2038X - (5.20 \times 10^{-6})\Delta H(X)$
3. High efficiency, 95 to 99.5 percent.
   - a. Low cost: $y = 14.51 + 0.2407X - (2.0 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 14.51 + 0.3132X - (8.0 \times 10^{-6})\Delta H(X)$

Low-voltage electrostatic precipitators (<50,000 acfm)

1. Low efficiency, 11 to 87 percent.
   - a. Low cost: $y = 0.7706 + 0.2374X - (0.075 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 0.7706 + 0.2568X - (0.300 \times 10^{-6})\Delta H(X)$
2. Medium efficiency, 88 to 94 percent.
   - a. Low cost: $y = 1.046 + 0.2877X - (0.14 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 1.046 + 3060X - (0.56 \times 10^{-6})\Delta H(X)$
3. High efficiency, 95 to 99.5 percent.
   - a. Low cost: $y = 1.378 + 0.4553X - (0.2 \times 10^{-6})\Delta H(X)$
   - b. High cost: $y = 1.378 + 0.4756X - (0.80 \times 10^{-6})\Delta H(X)$

Basically, the equations were derived by: (1) assuming four gas-flow rates (25,000; 50,000; 100,000; and 150,000 acfm) for each type of gas-cleaning equipment; (2) making assumptions to be used in calculating control costs; (3) estimating annual control cost for each type of gas-cleaning equipment at each gas volume; (4) writing an equation relating the calculated costs and assumed gas-flow rates; and (5) adjusting the equation for actual hours of operation. The procedure used to estimate the annual control costs in Step (3) above is:

1. Calculate the purchased cost of add-on gas-cleaning equipment.

   (X = acfm $\times 10^3$; y = dollars $\times 10^3$)

Wet scrubbers:

Low efficiency	$y = 1.257 + 0.145X$
Medium efficiency	$y = 2.886 + 0.228X$
High efficiency	$y = 2.886 + 0.228X$

Fabric filters:

Type "A". High-temperature synthetics, woven and felt Continuous automatic cleaning.

$$y = 1.448 + 0.838X$$

Type "B". Medium-temperature synthetics, woven and felt. Continuous automatic cleaning.

$$y = 3.478 + 448X$$

Type "C". Woven natural fibers. Intermittently cleaned; single compartment.

$$y = 2.658 + 0.325X$$

High-voltage electrostatic precipitators:

Low efficiency	$y = 19.695 + 0.318X$
Medium efficiency	$y = 31.243 + 0.441X$
High efficiency	$y = 42.413 + 0.623X$

Low-voltage electrostatic precipitators:

Low efficiency	$y = 3.219 + 0.968X$
Medium efficiency	$y = 3.599 + 1.140X$
High efficiency	$y = 4.030 + 1.312X$

2. Add the installation cost factor to the purchased cost to get total installed cost. The installation cost factor is expressed as a percentage of the purchase cost and includes items such as auxiliary equipment (fans, motors, ductwork, etc.), transportation of equipment, site preparation, and erection of equipment. The installation cost factor is assumed and varies according to the type and efficiency of the gas-cleaning equipment (Table 7-18).

3. Annualize the total installed cost. A factor known in engineering economy as the capital recovery factor permits the expression of the initial investment cost in terms of a uniform annual cost to account for depreciation of the control equipment plus an assumed 10 percent interest rate for financing the investment.

Table 7-18. ASSUMPTIONS USED FOR CONTROL COST ESTIMATES

Assumption	Gravity collectors			Cyclones			Wet scrubbers		
	L[a]	M[a]	H[a]	L	M	H	L	M	H
Inlet temperature, °F	750			750			500		
Collection efficiency, %	11 to 35	36 to 50	51 to 65	11 to 50	51 to 70	71 to 90	11 to 83	84 to 94	95 to 99
Installation factor, % of purchase cost	33	67	100	35	50	100	50	100	200
Years of depreciation	15	15	15	15	15	15	15	15	15
Interest rate, %	10	10	10	10	10	10	10	10	10
Overhead charges, % of I.C.	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Electricity, $/kW-hr L	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
M	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
H	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Hours of operation	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Maintenance cost, $/acfm L	0.005	0.005	0.005	0.005	0.005	0.005	0.02	0.02	0.02
M	0.015	0.015	0.015	0.015	0.015	0.015	0.04	0.04	0.04
H	0.025	0.025	0.025	0.025	0.025	0.025	0.06	0.06	0.06
Pressure drop, in. H_2O	0.5	0.5	0.5	2	3	4	5	15	60
Cost of water, $\$10^{-3}$/gal							0.35	0.50	1.00

Table 7-18 (continued). ASSUMPTIONS USED FOR CONTROL COST ESTIMATES

Assumption	Low-voltage ESP			High-voltage ESP			Fabric filters		
	L	M	H	L	M	H	L	M	H
Inlet temperature, °F	750			750			250 - 500		
Collection efficiency, %	11 to 87	88 to 94	95 to 99	11 to 87	88 to 94	95 to 99	All are >99		
Installation factor, % of purchase cost	40	70	100	40	70	100	50	75	100
Years of depreciation	15	15	15	15	15	15	15	15	15
Interest rate, %	10	10	10	10	10	10	10	10	10
Overhead charges, % of I.D.	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Electricity, $/kW-hr L	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
M	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
H	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Hours of operation	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Maintenance cost, $/acfm L	0.005	0.005	0.005	0.01	0.01	0.01	0.02	0.02	0.02
M	0.014	0.014	0.014	0.02	0.02	0.02	0.05	0.05	0.05
H	0.02	0.02	0.02	0.03	0.03	0.03	0.08	0.08	0.08
Pressure drop, in. H_2O	Neg	Neg	Neg	Neg	Neg	Neg	2 to 3	4 to 5	6 to 8
Cost of water, $\$10^{-3}$/gal									

[a] L = low efficiency; M = medium efficiency; H = high efficiency.

4. Add operating and maintenance costs to the annualized installed cost. This cost was based upon one variable: gas flow rate into the control equipment. Other variables – hours of operation of the control equipment, electricity costs, maintenance costs, pressure drops, and cost of water – used to calculate operating and maintenance were made constant.

5. Add annual overhead charges. These are charges for taxes and insurance and they are assumed to be 4 percent of the installed cost.

Sales tax on the purchased equipment, investment tax credits, and cost for disposing of collected particulates were not included in the estimates.

Procedures are given below for manually calculating the cost of add-on controls for particulate emissions from industrial processes.

1. From Table 7-19 determine the add-on equipment that is compatible with existing control equipment. Desired particulate collection efficiency can be calculated as $(1 - \frac{P_2}{100})\ 100$.

2. Estimate gas volumes for sizing add-on control equipment. Calculate the values missing from Table 7-20 by performing the lettered steps indicated in the column heatings.

   A. Ascertain the exit-gas volume (presented as given gas volume in steps B, C, and D) for respective industrial plant stacks.

   B. (Given gas volume) $\left(\frac{460 + 250}{460 + \text{Assumed gas temperature}}\right) =$

      Adjusted gas volume at 250° F

   C. (Given gas volume) $\left(\frac{450 + 500}{460 + \text{Assumed gas temperature}}\right) =$

      Adjusted gas volume at 500° F

   D. (Given gas volume) $\left(\frac{460 + 750}{460 + \text{Assumed gas temperature}}\right) =$

      Adjusted gas volume at 750° F

3. Determine annualized control costs by first referring to Table 7-19 to get the appropriate control equipment for the desired efficiency. Next, refer to Table 7-20 to get the adjusted gas volume to be used in the equations in Table 7-21 (X is in thousands of cubic feet per minute; $\Delta H = 8{,}760$ - actual hours of operation; C_L and C_H are in thousands of dollars).

7.3.3.1.2 Uncontrolled process sources. For sources with no existing gas-cleaning equipment, standard procedures could not be followed. For these sources, individual cost estimates based upon literature surveys were made to determine feasible control alternatives. Gas volumes to be handled by the equipment were estimated by converting given pounds of gas per hour to standard cubic feet per minute. If feasible control alternatives, gas volumes, and hours of operation are known, estimates of annual costs of control can be made. The above procedures were followed except where lack of information on pounds of gas per hour prevented conversion to a gas flow rate or where control costs could be calculated

Table 7-19. COMPATIBLE ADD-ON CONTROL EQUIPMENT FOR REMOVAL OF PARTICLES

Existing control equipment	Wet scrubbers, at 500° F			Electrostatic precipitators, at 750° F			Fabric filters, at 500° F or 250° F
	Assumed collection efficiency,[a] %			Assumed collection efficiency,[a] %			Assumed collection efficiency,[a] %
	11 to 83	84 to 94	95 to >99	11 to 97	84 to 94	95 to >99	11 to >99
Gravity collectors	x	x	x	x	x	x	x
Cyclones	x	x	x	x	x	x	x
Wet scrubbers	x	x	x	-	-	-	x
Electrostatic precipitators	-	-	-	x	x	x	-
							x
Fabric filters	-	-	-	-	-	-	x

[a] A lower limit of 11 percent is given because it was assumed that if a partially controlled source needed only 10 percent additional control or less to meet the particulate regulation, compliance would be obtained by improved maintenance practices with no capital expenditure.

Table 7-20. ESTIMATION OF ADJUSTED GAS VOLUMES FOR DETERMINING SIZE OF ADD-ON CONTROL EQUIPMENT

Existing control equipment	Given gas volume A	Assumed gas temperature, °F	Adjusted gas volume		
			250° F B	500° F C	700° F D
Gravity collectors		750			
Cyclones		750			
Wet scrubbers		500			
Electrostatic precipitators		750			
Fabric filters		500			

Table 7-21. ANNUAL COSTS FOR ADD-ON CONTROL EQUIPMENT

Control equipment	Efficiency, %	Annual cost, $\$10^3$
Wet scrubbers	11 to 83	$C_L = 0.3224 + 0.1088X - (4.83 \times 10^{-6})\Delta H(X)$
		$C_H = 0.3224 + 0.2716X - (18.89 \times 10^{-6})\Delta H(X)$
	84 to 94	$C_L = 0.987 + 0.2146X - (13.03 \times 10^{-6})\Delta H(X)$
		$C_H = 0.987 + 0.6152X - (51.70 \times 10^{-6})\Delta H(X)$
	95 to >99	$C_L = 1.481 + 0.6470X - (55.91 \times 10^{-6})\Delta H(X)$
		$C_H = 1.481 + 2.2202X - (223.21 \times 10^{-6})\Delta H(X)$
Electrostatic precipitators Low voltage, <50,000 acfm	11 to 87	$C_L = 0.7706 + 0.2374X - (0.075 \times 10^{-6})\Delta H(X)$
		$C_H = 0.7706 + 0.2568X - (0.300 \times 10^{-6})\Delta H(X)$
	88 to 94	$C_L = 1.046 + 0.2877X - (0.14 \times 10^{-6})\Delta H(X)$
		$C_H = 1.046 + 0.3060X - (0.56 \times 10^{-6})\Delta H(X)$
	95 to 99.5	$C_L = 1.378 + 0.4553X - (0.2 \times 10^{-6})\Delta H(X)$
		$C_H = 1.378 + 0.4756X - (0.80 \times 10^{-6})\Delta H(X)$
Electrostatic precipitators High voltage	11 to 87	$C_L = 4.714 + 0.0944X - (0.95 \times 10^{-6})\Delta H(X)$
		$C_H = 4.714 + 0.1394X - (3.8 \times 10^{-6})\Delta H(X)$
	88 to 94	$C_L = 9.082 + 0.1497X - (1.3 \times 10^{-6})\Delta H(X)$
		$C_H = 9.082 + 0.2038X - (5.20 \times 10^{-6})\Delta H(X)$
	95 to 99.5	$C_L = 14.51 + 0.2407X - (2.0 \times 10^{-6})\Delta H(X)$
		$C_H = 14.51 + 0.3132X - (8.0 \times 10^{-6})\Delta H(X)$
Fabric filters	Type "A"	$C_L = 0.373 + 0.3299X - (3.9 \times 10^{-6})\Delta H(X)$
	>99	$C_H = 0.496 + 0.5044X - (15.6 \times 10^{-6})\Delta H(X)$
	Type "B"	$C_L = 0.893 + 0.1995X - (3.9 \times 10^{-6})\Delta H(X)$
	>99	$C_H = 0.900 + 0.2679X - (15.6 \times 10^{-6})\Delta H(X)$

on the basis of historical data generated by industrial control cost studies. As an example, cupola melt rates from grey-iron foundries can be used as a basis for estimating annual control costs.

7.3.3.2 Sulfur Dioxide Emissions — Standard procedures have not been developed for estimating the annual costs of reducing sulfur dioxide emissions from industrial processes. Individual cost estimates were based, therefore, on literature surveys. In general, however, the control techniques given in Table 7-22 were used as a basis for estimating annual control costs.

The annual cost for wet scrubbing with soda ash liquor was determined by using information taken from an article by Kopita and Gleason.[11] An equation was developed from this information and is given as follows:

$$\text{Annual cost} = \$48S + \left(\frac{\text{scfm}}{55{,}000}\right)^{0.6} (\$25{,}000) + \$(\text{scfm})\frac{1}{2}$$

Table 7-22. SULFUR DIOXIDE CONTROL TECHNIQUES

Source code	Source type	Control technique
14	H_2S flare	Replace with incinerator; wet scrubbing with soda ash liquor
19	H_2SO_4 manufacturing	Double-absorption-contact acid plant
23	H_2SO_4 manufacturing	Double-absorption-contact acid plant
26	Pulp liquor process	Wet scrubbing with soda ash liquor
35	Coke oven process	Wet scrubbing with soda ash liquor
36	H_2SO_4 manufacturing	Double-absorption-contact acid plant
64	Glass melting	Wet scrubbing with soda ash liquor
69	Open burning	Convert to sanitary landfill
117	Process fluid coker	Electrostatic precipitator; wet scrubbing with soda ash liquor
118	Sulfur plant	Wet scrubbing with soda ash liquor
120	Open burning	Convert to sanitary landfill
433	H_2S flare	Replace with incinerator; wet scrubbing with soda ash liquor
436	Carbon black plant (dryer)	Wet scrubbing with soda ash liquor
450	Sulfur plant	Wet scrubbing with soda ash liquor
451	Gear oil manufacturing	Wet scrubbing with soda ash liquor
452	H_2S flare	Replace with incinerator; wet scrubbing with soda ash liquor
453	Catalytic cracker	Electrostatic precipitator; wet scrubbing with soda ash liquor
476	H_2S flare	Replace with incinerator; wet scrubbing with soda ash liquor
477	H_2S flare	Replace with incinerator; wet scrubbing with soda ash liquor
479	Sulfur plant	Wet scrubbing with soda ash liquor
480	Glass furnace	Wet scrubbing with soda ash liquor
481	Glass furnace	Wet scrubbing with soda ash liquor
494	Catalytic cracker	Wet scrubbing with soda ash liquor

where S = tons of SO_2 removed; scfm = gas flow of process.

The annual cost for replacing H_2S flares with incinerators was determined by first estimating low and high investment costs for incinerators. Next, annual capital charges were assumed to be 20 percent of the investment cost. It was assumed that fuel costs will be the same with the incinerator as with the flares; therefore, the incremental operating cost will be zero. The total annual cost for replacement was the low and high annual capital charges.

The annual cost for converting open burning to sanitary landfill was \$0.30 per ton of refuse burned annually. This is based upon the National Solid Waste Survey. The annual cost of the double-absorption-contact acid plant is based upon a low and a high cost per ton of SO_2 removed. The low estimate is \$12.59 per ton of SO_2 removed; the high estimate is \$26.59 per ton of SO_2 removed. These figures are taken from the National Emission Standard Study, Appendix E, November 1969. The annual cost of electrostatic precipitators, which are sometimes needed to preclean gas going to the wet scrubber, is based upon equations given in Section 7.3.3.1 of this report.

7.4 REFERENCES FOR SECTION 7

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